UPDATED DISTRIBUTION AND REINTRODUCTION OF

THE LOWER KEYS MARSH RABBIT

A Thesis

by

CRAIG ALAN FAULHABER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Wildlife and Fisheries Sciences

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Approved as to style and content by:

Nova J. Silvy (Chair of Committee)	Markus J. Peterson (Member)
X. Ben Wu (Member)	Robert D. Brown (Head of Department)

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ABSTRACT

Updated Distribution and Reintroduction of
the Lower Keys Marsh Rabbit. (December 2003)
Craig Alan Faulhaber, B.A., Wittenberg University
Chair of Advisory Committee: Dr. Nova J. Silvy

Listed as federally-endangered in 1990, the Lower Keys marsh rabbit (LKMR, *Sylvilagus palustris hefneri*) exists as a metapopulation in patches of wetland habitat in Florida's Lower Keys. This study sought to address 2 priority actions identified by the LKMR Recovery Team: (1) monitoring of populations and (2) reintroduction. Monitoring the distribution and status of LKMR populations is critical for targeting future management actions. Informal transects for rabbit fecal pellets were used to survey habitat patches documented in1988–1995 surveys and to identify additional patches of occupied and potential habitat. Next, a buffer was created around patches to help managers account for uncertainty in rabbit movements and to identify groups of patches that might function as local populations. Surveys included 228 patches of occupied and potential habitat, 102 of which were occupied by rabbits. Patches were arranged in 56 occupied and 88 potential populations. Surveys revealed new patches of both occupied and potential habitat. Considering only areas included in 1988–1995 surveys, however, revealed a net decrease in the number of occupied patches. Many of the recently extirpated populations, which tended to occupy the periphery of larger islands or small neighboring islands, were unlikely to be recolonized without human intervention. Reintroduction provides a means of artificially recolonizing potential habitat. Two pilot reintroductions were conducted to evaluate this conservation strategy for the species. The second reintroduction was postponed, but the first effort met all criteria for short-term success, including survival comparable to a control group, fidelity to release sites, and evidence of reproduction. There are a limited number of potential source populations for translocations. Future efforts should consider using *in-situ* captive breeding to prevent potential long-term impacts to these populations. Few potential release sites exhibited suitable habitat quality and landscape context. Thus, for reintroduction to be more widely-applied for this species, it must be part of a comprehensive management plan involving land acquisition, control of secondary impacts from development, and habitat restoration and enhancement.

ACKNOWLEDGMENTS

I thank Dr. Nova J. Silvy for all of his guidance and support on this project and for being so patient and generous with his time. Dr. Phil Frank of the Florida Keys National Wildlife Refuges and Dr. Roel Lopez provided invaluable advice and support throughout the study. This project would not have been possible without them. I thank Dr. Markus J. Peterson for his constructive comments on my proposal and thesis and for his excellent teachings both inside and outside of the classroom. Dr. X. Ben Wu provided assistance with spatial analyses and opened my eyes to the world of landscape ecology.

Funding for this project was provided by the U. S. Fish and Wildlife Service (Ecological Services and the Florida Keys National Wildlife Refuges), Florida Department of Transportation, National Fish and Wildlife Foundation, and Texas A&M University. I thank Pat McNeese, Susan Sprunt, and Jeanette Hobbs of the Florida Keys Environmental Restoration Trust Fund, who administered the National Fish and Wildlife Foundation grant. The Florida Fish and Wildlife Conservation Commission provided permits for this study.

I am grateful to all of the staff (past and present) of the National Key Deer Refuge, who provided tremendous logistical support throughout this project. I also thank the staff of the Department of Wildlife and Fisheries Sciences for all of their efforts behind the scenes. Naval Air Facility, Key West, was generous in granting me access to rabbit habitat on Boca Chica, Geiger, East Rockland, and the Saddlebunch keys. I am thankful for the advice and assistance of Naval Air Facility, Key West's Natural Resource Managers, Arnim Schuetz and Edward Barham. I also thank Philip Hughes and Tylan Dean of the U.S. Fish and Wildlife Service, Ecological Services, for their advice and interest in the project. Kim Rohrs of the Monroe County Department of Planning and Environmental Resources provided valuable spatial and tabular data on land ownership and land-use planning in the Keys.

My interns, Josh Harris, Kyle Melton, Jana Mott, and Brad Porter contributed many long hours of fieldwork, as did U.S. Fish and Wildlife interns P. J. Stevko and Melanie Howey. Others who helped with the field work included Anthony Braden, Ben Edwards, Ned and Margo Faulhaber, Eddie Lyons, Neil Perry, and Nils Peterson. Bart Hovanic helped me locate new areas of potential rabbit habitat.

I am grateful to Mark Barrett, Neil Perry, and T. Wayne Schwertner for their sage advice and for many long and valuable discussions about the project. Anthony Braden also provided advice and comments on portions of this thesis.

Dr. Nancy Thomas and Dr. Grace McLaughlin of the National Wildlife Health Center performed a necropsy for this study. Dr. John Whitaker of Indiana State University identified ectoparasites for the project. Dr. Richard Wunderlin of the University of South Florida and Vic Anderson of the Army Corps of Engineers helped to identify plant specimens.

Moral support during this project was provided by numerous friends, to whom I am most grateful. Many of my mentors contributed indirectly to this project, including Dr. Tim Lewis, Dr. Nathan Bolls, Dr.

Reed Bowman, Abdelwahab Sinnary, Dr. Wayne Vos, and Richard Hatfield. Above all, I thank my parents, Margo and Bud Faulhaber, and my brother Ned for their constant love and support.

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CHAPTER I

INTRODUCTION

INTRODUCTORY NOTES

The purpose of this chapter is to provide the reader with an introduction to the Lower Keys marsh rabbit (LKMR), its environment, and the issues that sparked this investigation. Understanding the ecology of the LKMR requires an understanding of the environment in which it lives. Therefore, a brief overview of the LKMR is followed by a detailed discussion of the Lower Keys of Florida. Next, the ecology and conservation status of the LKMR are discussed in greater detail, and the chapter concludes with an overview of the study's objectives.

The LKMR is one of 3 subspecies of *Sylvilagus palustris*. It differs from the other subspecies in several aspects of its cranial morphology, including an elongated dentary symphysis, shortened molariform tooth row, relatively high and convex frontonasal profile, and a rather broad cranium (Lazell 1984). The nominate subspecies ranges from the Dismal Swamp in southern Virginia through southern Georgia (Fig. 1.1, Lazell 1984). *S. p. paludicola* is distributed throughout mainland Florida and into the Upper and Middle keys as far south as Long Key (Schwartz 1952, Layne 1974) (Figs. 1.1, 1.2). The LKMR is endemic to Florida's Lower Keys, which form the end of a string of limestone islands curving in a southwesterly direction from the southern tip of Florida (Fig. 1.2). The Lower Keys extend over 60 km from Little Duck Key (24°41'N, 81°14'W) to Key West (24°33'N, 81° 49'W). Moser Channel, measuring nearly 11km, separates the Middle and Lower keys and likely provided the geographic isolation necessary for the differentiation of the LKMR (Lazell 1984, Fig. 1.2).

THE LOWER KEYS

Geologic History

At various times during their history, the Lower Keys have been both completely covered by the ocean and connected to mainland Florida. At the end of the Sangamon Interglacial period, some 100,000 years before present (YBP), the Lower Keys were nothing more than layers of ooids (precipitated grains of calcium carbonate) covered by the ocean and separated by tidal channels (Mueller and Winston 1997). Sea level dropped as the Wisconsonian Glaciation succeeded the Sangamon Interglacial period, and the future Lower Keys became part of a vastly expanded Florida peninsula (Mueller and Winston 1997). The exposed ooids hardened into Miami oolite, the rock that forms the basis of the Lower Keys. Sea level rose dramatically 15,000–10,000 YBP, and the present day Lower Keys were formed (Mueller and Winston

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This thesis follows the style and format of the Journal of Wildlife Management.

1997). This rise in sea level provided geographic isolation for some wildlife populations, resulting in the evolution of endemic subspecies in the Lower Keys, including the Key deer (*Odocoileus virginianus clavium*) and the LKMR (Lazell 1984).

Climate

Although the Lower Keys are situated outside the tropics, the climate is considered tropical due to the warming influence of the Gulf of Mexico and the Gulf Stream (Jordan 1997). The mean annual temperature in Key West, Florida from 1971-2000 was 25.6 C, ranging from a mean of 21.3 C in January to a mean of 29.3 C in July (National Climatic Data Center 2001). Annual precipitation at Key West averaged 989 mm from 1971-2000 (National Climatic Data Center 2001). Approximately 70% of the annual precipitation takes place mid-May–mid-November (Ross et al. 1994). Tropical storm and hurricane formation are most likely to occur June–November (Jordan 1997). Each year, there is a 1 in 7 chance that hurricane-force winds will strike Key West (Jordan 1997).

Vegetation Associations

In the Lower Keys, it is uncommon to find areas with an elevation > 2 m (Ross et al. 1994). Small variations in elevation, however, lead to striking changes in vegetation associations. As elevation increases, vegetation types transition from mangroves to saltmarsh/buttonwood transition zone to upland areas of hammocks and pinelands (Fig. 1.3). In low-lying areas not influenced by tides, freshwater pine flats, freshwater marsh, and freshwater hardwoods also are present (Fig. 1.3). Coastal beach berms can be found along some coastlines in the Lower Keys (Fig. 1.3). Each of these vegetation types is described below.

Mangroves.-- Also referred to as tidal swamps or tidal forests, mangroves are characterized by dense forests in relatively flat intertidal and supratidal areas with low wave energy (Florida Natural Areas Inventory 1990, Odum and McIvor 1990, Fig. 1.4). Mangroves are often inundated with water at high tides, and the soil is saturated with water even at low tides (Florida Natural Areas Inventory 1990). Three species dominate this vegetation association: (1) red mangrove (*Rhizophora mangle*), (2) black mangrove (*Avicennia gerimans*), and (3) white mangrove (*Laguncularia racemosa*). These species are all adapted to living in environments characterized by unstable soils, high salinity, and varying water levels (Odum and McIvor 1990). A fourth woody species, buttonwood (*Conocarpus erectus*) is common at higher elevations within the mangrove community.

Ross et al. (1992) further subdivided the mangrove community into Peaty Mangrove Forest, Peaty Mangrove Woodland, and Dwarf Mangrove Mudflats. Peaty Mangrove Forest, which is dominated by red mangroves, and Peaty Mangrove Woodland, dominated by black mangroves, occupy areas with organic soils. Dwarf Mangrove Mudflats, or scrub mangrove communities, are characterized by low shrubs (<2 m in height) in areas of calcareous mud (Figs. 1.3, 1.5).

Saltmarsh/Buttonwood Transition Zone.-- Between the mangroves and the upland vegetation types (hardwood hammock and pineland) lies the saltmarsh/buttonwood transition zone. The vegetative composition and duration of flooding in this zone varies widely throughout Florida (see Montague and Wiegert 1990 for a review). In the Lower Keys, the lowest portions of the saltmarsh/buttonwood zone are

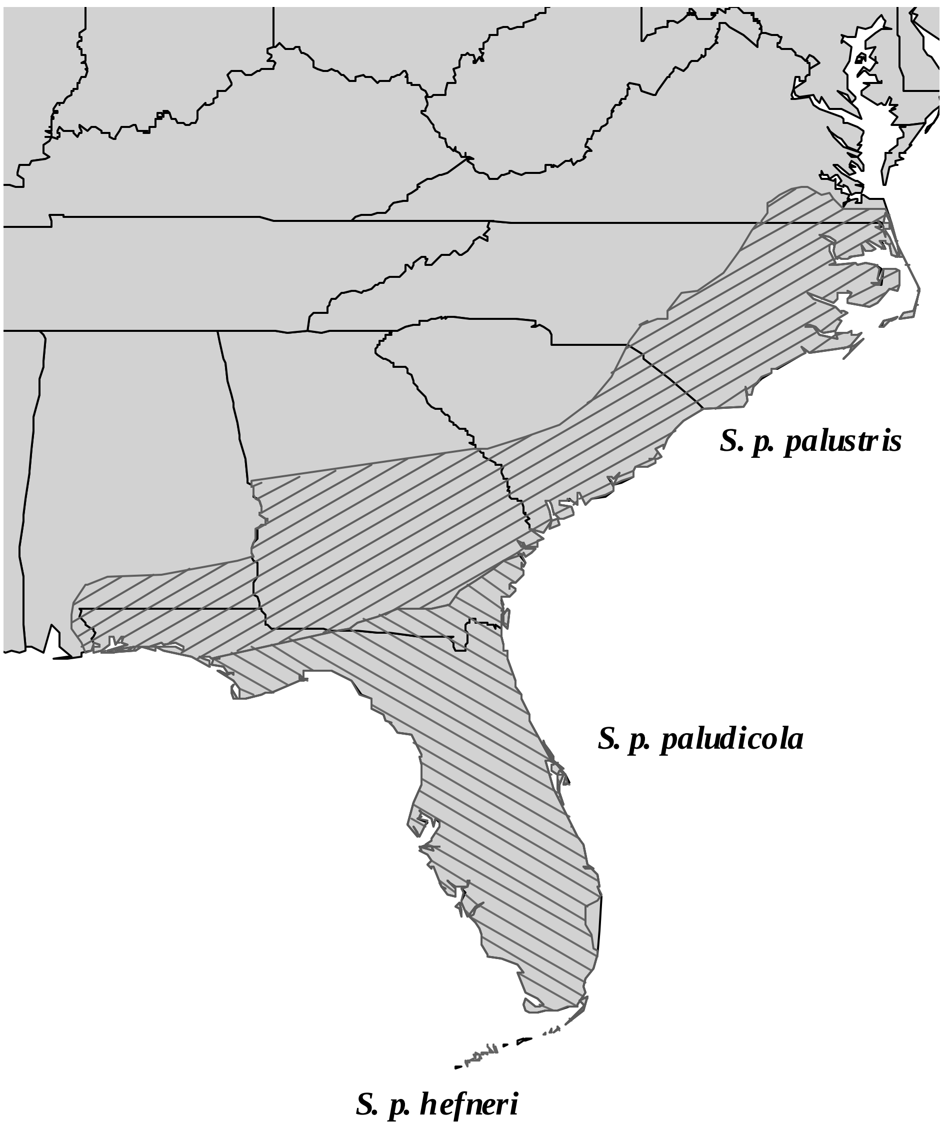

Fig. 1.1. Distribution of the 3 subspecies of marsh rabbit in the U. S. (adapted from Whitaker and Hamilton 1998).

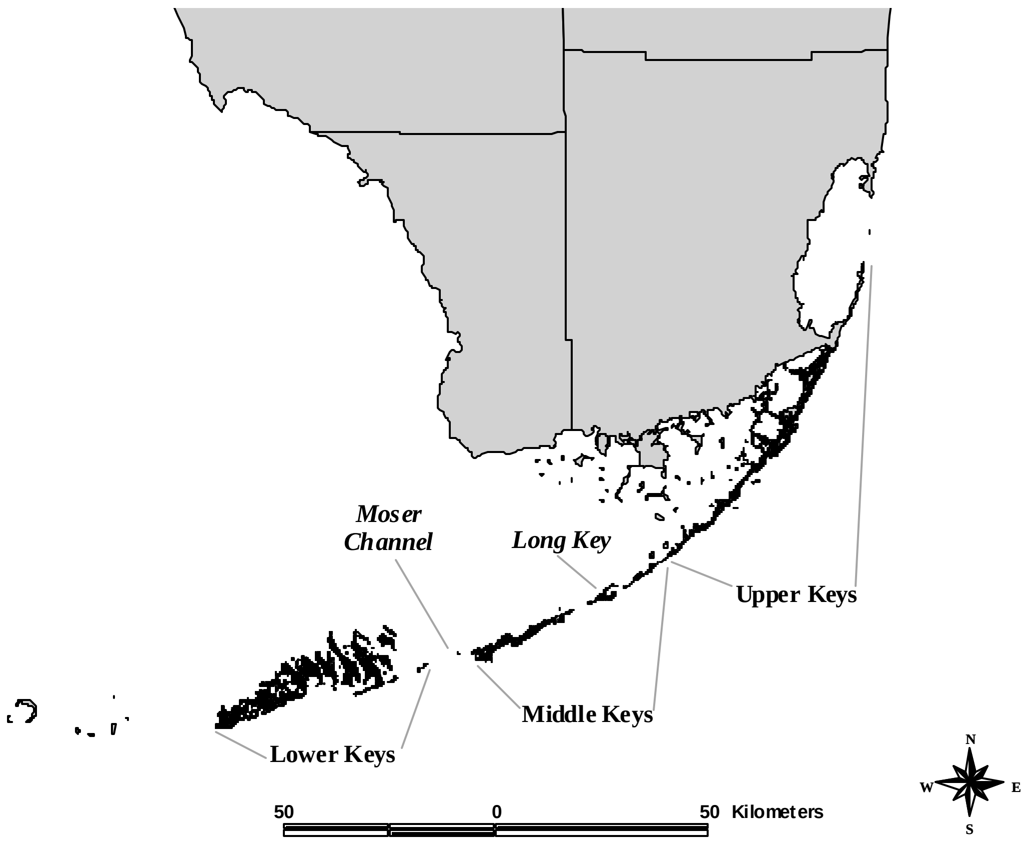

Fig. 1.2 The Florida Keys extend in a southwesterly arc from the tip of south Florida. The chain of islands can be separated into the Upper, Middle, and Lower keys. The mainland subspecies extends south to Long Key. Moser Channel probably provided the geographic isolation necessary for the evolution of the Lower Keys marsh rabbit.

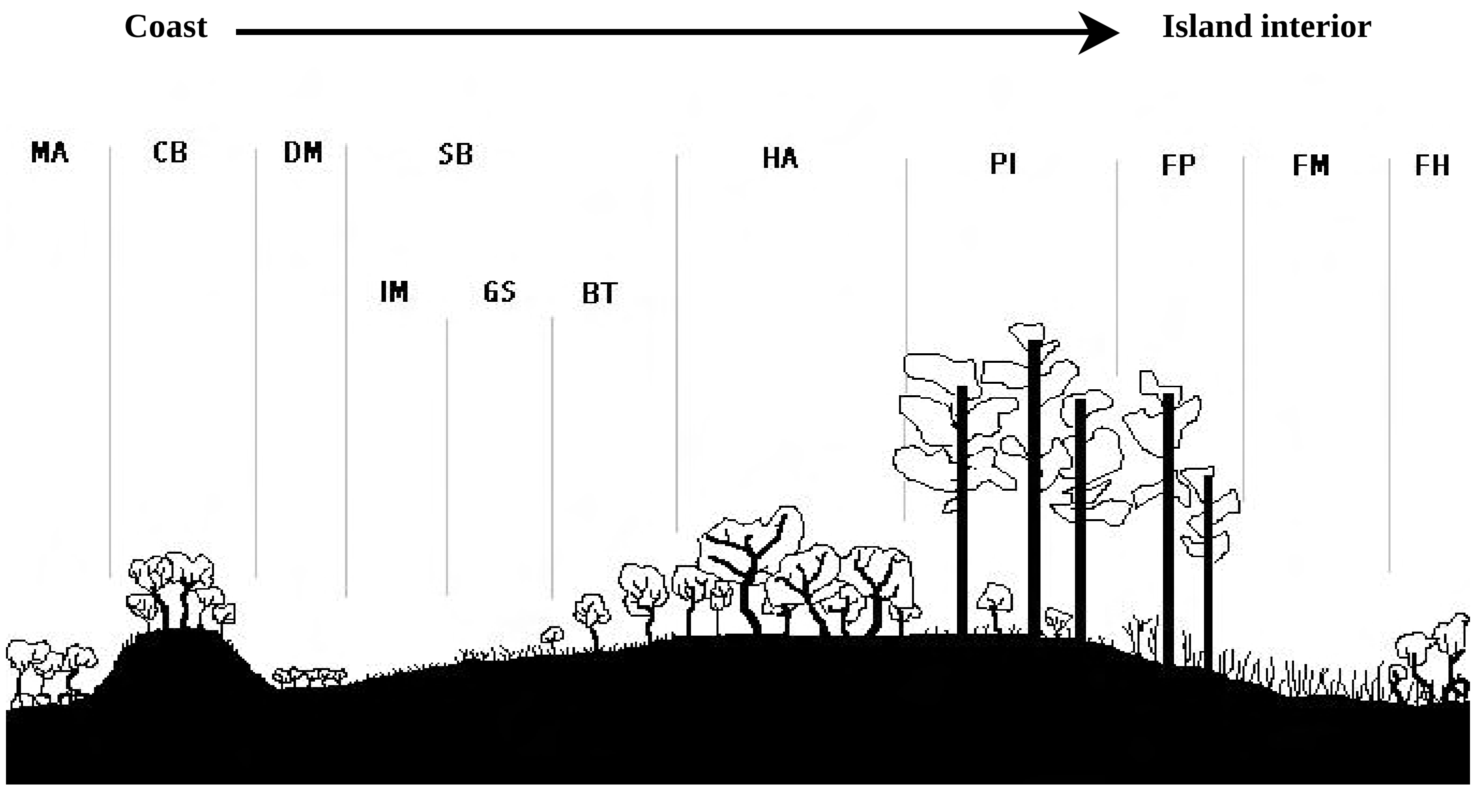

Fig. 1.3. Vegetation types of the Lower Keys of Florida, USA. MA = mangroves, CB = coastal beach berm, DM = dwarf mangrove mudflats, SB = saltmarsh/buttonwood transition zone, IM = intertidal marsh, GS = grassy saltmarsh, BT = buttonwood transitional, HA = hammock, PI = pineland, FP = freshwater pine, FM = freshwater marsh, FH = freshwater hardwoods.

Fig. 1.4. Areas that are constantly or periodically inundated with saltwater, such as this area on Big Pine Key, support the mangrove community.

Fig. 1.5. Black mangroves dominate this dwarf mangrove mud flat on Big Pine Key. Note the light color of the calcareous soil.

Fig. 1.6. The intertidal marsh occurs in the lowest elevations of the saltmarsh/buttonwood transition zone. This photo was taken by N. Perry, Texas A&M University, on Sugarloaf Key.

Fig. 1.7. This grassy saltmarsh on Boca Chica Key is dominated by gulf cord grass and sea daisy.

Fig. 1.8. Buttonwood transitional areas, such as this one in the Saddlebunch Keys, possess a buttonwood canopy and an understory of grasses, Cyperaceae, and shrubs.

Fig. 1.9. Hammocks, like this area on No Name Key, contain a wide variety of woody species but often exhibit little vegetation in the herbaceous layer.

periodically inundated by windblown tides and a seasonal rise in sea level (Ross et al. 1992). Areas of higher elevation within this zone, although rarely inundated, are influenced by saline groundwater and soils (Montague and Wiegert 1990, Williams 1997). Thus, the saltmarsh/buttonwood zone is occupied by halophytic plant species.

Due to the variability in plant species composition that exists within the saltmarsh/buttonwood transition zone, alternative classification systems exist (e.g., Ross et al. 1992, Williams 1997). In my thesis, however, the saltmarsh/buttonwood zone will be described using the terms of Forys (1995), McNeese and Taylor (1998), and the U. S. Fish and Wildlife Service (USFWS) (1999). According to McNeese and Taylor (1998) and the USFWS (1999), the saltmarsh/buttonwood zone in the Florida Keys can be subdivided into 3 vegetation types: (1) intertidal marsh, (2) grassy saltmarsh, and (3) buttonwood transitional (Fig. 1.3).

Occupying the lowest elevations of the saltmarsh/buttonwood zone, intertidal marsh includes open areas of low halophytic vegetation that are periodically inundated with saltwater (Figs. 1.3, 1.6). Dominant species include glasswort (*Salicornia spp.*), key grass (*Monanthochloe littoralis*), and saltwort (*Batis maritima*). Scattered tree species include the 3 mangrove species (especially black mangrove) and buttonwood.

Occurring at slightly higher elevations, grassy saltmarsh is dominated by salt-tolerant grasses, Cyperaceae, and some shrubs (Figs. 1.3, 1.7). Tree species, especially buttonwood, are present but not dominant, leaving the grassy saltmarsh fairly open. Forys (1995) subdivided the grassy saltmarsh into a "mid marsh" dominated by seashore dropseed (*Sporobolus virginicus*) and sea daisy (*Borrichia frutescens*) and a "high marsh" dominated by gulf cord grass (*Spartina spartinae*) and saltmarsh fringe-rush (*Fimbristylis castanea*). Whereas other authors (e.g., Montague and Wiegert 1990) use the term "high marsh" to refer to any area above mean high water, Forys limits the phrase to a portion of the grassy saltmarsh. In my thesis, "high marsh" will be used as in Forys (1995). Other common herbaceous species in the grassy saltmarsh include saltmeadow cordgrass (*Spartina patens*) and saltgrass (*Distichilis spicata*).

Buttonwood transitional areas occur at higher elevations within the saltmarsh/buttonwood transition zone, often adjacent to hammocks (Fig. 1.3). Dominated by buttonwood trees, these areas have a relatively open canopy that allows sunlight to penetrate to the ground (Fig. 1.8). Groundcover is often comprised of grasses, Cyperaceae, and shrubs. Common species include seashore dropseed, sea daisy, sea oxeye (*Borrichia arborescens*), and saltgrass.

Hammocks.-- Tropical hardwood hammocks, herein referred to as hammocks, are composed primarily of broadleaf, evergreen, or semi-evergreen tree species common to the Bahamas and Greater Antilles (Snyder et al. 1990, Nielsen 1997, Fig. 1.9). Hammocks can be found in upland areas with organic soils and often occur in the Lower Keys as discrete stands (Snyder et al. 1990). Herbaceous epiphytes are common, but understory vegetation is generally lacking, except on hammock margins or in canopy gaps

(Snyder et al. 1990). Common woody species in Lower Keys hammocks include white stopper (*Eugenia axillaris*), Spanish stopper (*Eugenia foetida*), poisonwood (*Metopium toxiferum*), Jamaica dogwood (*Piscidia piscipula*), wild dilly (*Manilkara bahamensis*), Key thatch palm (*Thrinax morrisii*), pigeon plum (*Coccoloba diversifolia*), blolly (*Guapira discolor*), and gumbo limbo (*Bursera simaruba*) (M. Barrett, University of South Florida, unpublished data; Snyder et al. 1990). As the hammocks transition into the saltmarsh/buttonwood zone, the tree species become scrubbier, and species such as saffron plum (*Bumelia celastrina*), sea grape (*Coccoloba uvifera*), black torch (*Erithalis fruticosa*), joewood (*Jacquinia keyensis*), and blackbead (*Pithecellobium guadalupense*) become more common (Snyder et al. 1990).

Pineland.-- Slash pine (*Pinus elliottii* var. *densa*) forms an open canopy in this upland community (Fig. 1.10). Fire largely determines the extent of the subcanopy and understory vegetation. Areas that are burned frequently support a variety of shrubs, grasses, and herbs (Ross et al. 1992). With the exception of Key thatch palm and silver palm (*Coccothrinax argentata*), subcanopy trees are generally lacking (Snyder et al. 1990). In contrast, a dense canopy of broadleaf evergreen trees and a lack of herbaceous understory characterize areas that have not been burned recently (Ross et al. 1992). If fires are suppressed long enough, the pineland will slowly change to hammock (Hardin 1997). Common woody species in pineland include locust berry (*Byrsonima lucida*), pisonia (*Pisonia rotundata*), long-stalked stopper (*Psidium longipes*), and yellow root (*Morinda royoc*) (M. Barrett, University of South Florida, unpublished data). Common herbaceous species include three-awn (*Aristida purpurascens*), muhly grass (*Muhlenbergia spp*.), several bluestem species (*Andropogon spp*.), rattlebox (*Crotalaria pumila*), Big Pine partridge pea (*Cassia keyensis*), and pine fern (*Anemia adiantifolia*) (Florida Natural Areas Inventory 1990, Hardin 1997). The distribution of the pineland community coincides with the presence of permanent fresh water (Ross et al. 1994). Thus, extensive pinelands are found only on keys that are large enough to possess an underground freshwater lens (Ross et al. 1992).

Freshwater wetlands.-- In the Lower Keys, the nature of the Miami oolite facilitated both the formation of freshwater lenses and the formation of 3 types of freshwater wetlands: (1) freshwater pine flats, (2) freshwater hardwood forest, and (3) freshwater marsh (McGarry MacAulay et al. 1994, Kruer 1997). These wetlands occur in low-lying areas where the water table is close to the surface or in inland depressions that collect precipitation. The amount (or presence) of water in these wetlands is controlled by precipitation and thus varies seasonally (Ross et al. 1992).

In freshwater pine flats, slash pines form the canopy, and the understory is dominated by saw grass (*Cladium jamaicense*) and saw palmetto (*Serenoa repens*) (McGarry MacAulay et al. 1994, Fig. 1.11). Freshwater hardwood forests possess a canopy of broadleaf trees or shrubs (McGarry MacAulay et al. 1994), often with an understory of saw grass (Fig. 1.12). Common woody species include buttonwood, red mangrove, white mangrove, poisonwood, and wax myrtle (*Myrica cerifera*).

Fig. 1.10. An open canopy of slash pine characterizes pinelands in the Lower Keys. This photo was taken on Big Pine Key

Fig. 1.11. The prevalence of saw grass in freshwater pine flats, such as this area on Big Pine Key, indicates the presence of fresh water near the surface.

Fig. 1.12. Freshwater hardwood forests often contain buttonwood and mangrove trees and saw grass.

Fig. 1.13. This freshwater marsh on Big Pine Key is dominated by saw grass with some small buttonwood shrubs.

Fig. 1.14. Coastal beach berm vegetation occurs on mounds of storm-driven material, such as this area on Big Pine Key.

Fig. 1.15. Invasive exotic plant species can form monotypic stands, such as this clump of Australian pine on Boca Chica Key. Mangroves appear in the foreground. Photo taken by N. Perry, Texas A&M University.

Freshwater marshes are characterized by open expanses of Cyperaceae, especially saw grass (Ross et al. 1992, Fig. 1.13). *Eleocharis cellulosa* also is a common occupant of Lower Keys freshwater marshes. Scattered trees, such as buttonwood and red mangrove, may be present.

Coastal Beach Berm.-- Coastal beach berm vegetation is characterized by trees, shrubs, and xerophytic plants occupying mounds of storm-driven material parallel to coastlines (Florida Natural Areas Inventory 1990, Fig. 1.14). Coastal beach berms are quite variable in their species composition (Ross et al. 1992), but typical species include gumbo limbo, seagrape, Jamaica dogwood, blolly, seven year apple (*Casasia clusiifolia*), Spanish stopper, limber caper (*Capparis flexuosa*), blackbead, and Bahama nightshade (*Solanum bahamense*) (Ross et al. 1992, McGarry MacAulay et al. 1994). Various grasses and sedges also may be found on the sides of the berm. Coastal beach berms are relatively rare in the Lower Keys (USFWS 1999).

Exotics.-- Invasive exotic plant species are common in the Lower Keys and can form thick monotypic stands in some areas (Fig. 1.15). Common invasive exotic species include Australian pine (*Casuarina equisitifolia*), brazilian pepper (*Schinus terebinthifolia*), lead tree (*Leucaena leucocephala*), latherleaf (*Colubrina asiatica*), and mahoe (*Hibiscus tiliaceus*).

Development History and Land Use

Although they make up only a small portion of the county's land area, the Florida Keys contain most of the human population of Monroe County, Florida. From 1870–2000, the population of all of the Florida Keys grew from 5,657 to 79,589 (Monroe County Board of County Commissioners 2002). During the winter months, semi-permanent residents and tourists cause a population increase of an additional 75% (Gallagher 1997). Development throughout the Florida Keys increased significantly after World War II. From 1940–1960, 33,800 new residents were added to the Keys, and the population surged again from 1970–1990 (Monroe County Growth Management Division 1993). During the past several decades, population growth shifted from incorporated areas (e.g., Key West) to the unincorporated portions of the county (Monroe County Growth Management Division 1993).

Despite this population pressure, by the early 1990s, nearly 40% of the Lower Keys consisted of vacant, undeveloped land (Monroe County Growth Management Division 1993). In addition, government and private organizations had acquired 25% of the total land area in the Lower Keys for conservation (Monroe County Growth Management Division 1993). Much of this land is managed and owned by the USFWS's Florida Keys Wildlife Refuges. Endangered wildlife, such as the Florida Key deer, LKMR, and silver rice rat (Orozymys argentatus) rely on both the conservation and vacant land for habitat. Wildlife habitat for threatened and endangered species also can be found on some of the land owned by the U. S. military, which manages 1,300 ha on Boca Chica, East Rockland, Saddlebunch, and Cudjoe keys (Monroe County Growth Management Division 1993).

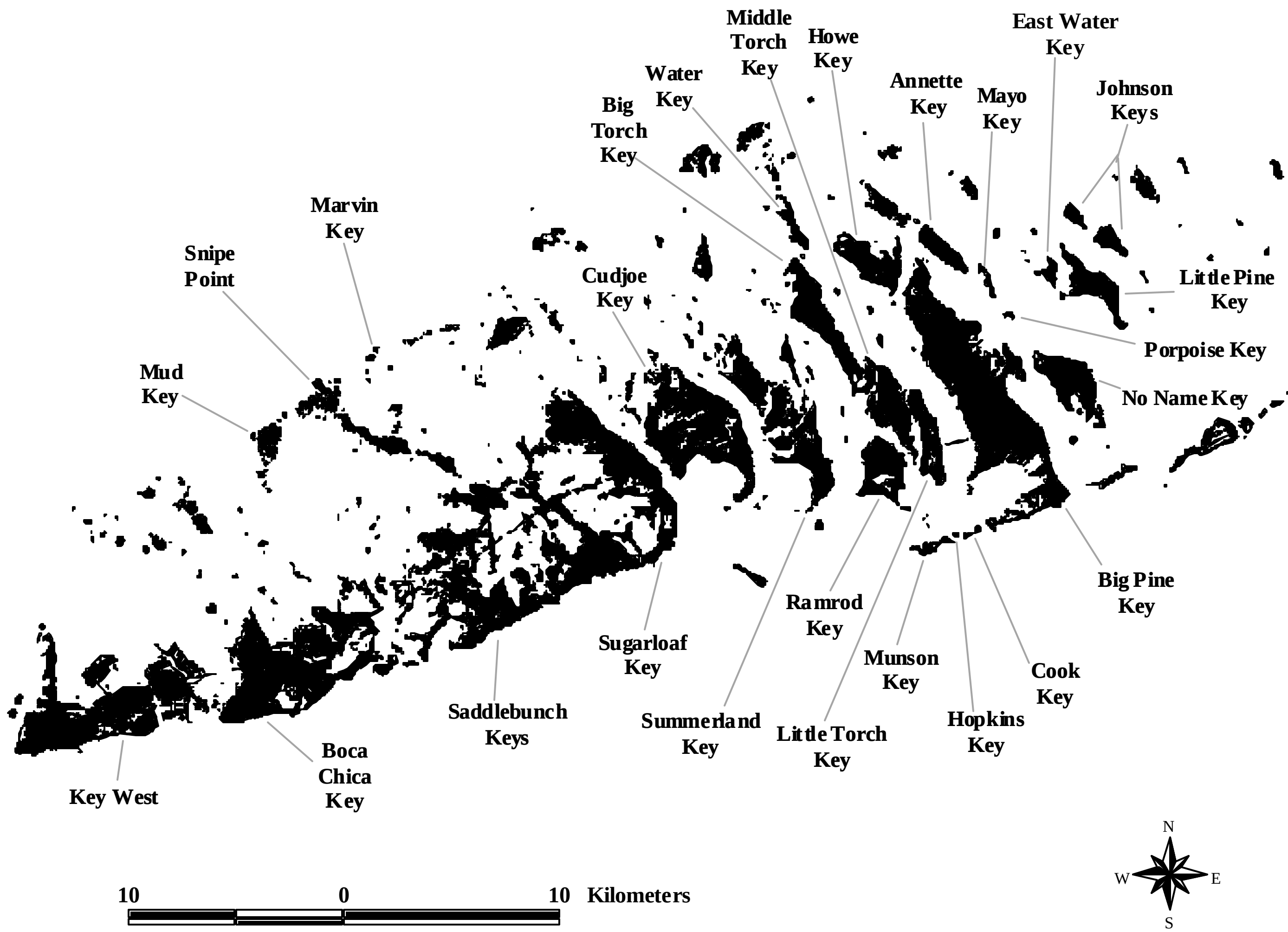

Fig. 1.16. The range of the Lower Keys marsh rabbit extends from Big Pine Key and its surrounding islands to Boca Chica Key. Keys known to have Lower Keys marsh rabbit habitat or potential habitat are labeled.

THE LOWER KEYS MARSH RABBIT

Description

The LKMR can be found from Big Pine Key and its surrounding islands to Boca Chica Key, though historically they probably occupied all islands with suitable habitat in the Lower Keys (Forys 1995, Forys et al. 1996, USFWS 1999) (Fig. 1.16). Forys et al. (1996) found most LKMR populations on 4 main keys connected to U. S. Highway 1: Boca Chica, Saddlebunch, Lower Sugarloaf, and Big Pine keys (Fig. 2.15).

The LKMR possesses a brown dorsal pelage, gray ventral pelage, and inconspicuous brown and gray tail. The pelage of rabbits on Big Pine Key can be somewhat lighter in color than other LKMRs, and parts of the ventral pelage may be nearly white (Lazell 1989). The LKMR has relatively short ears and slender feet compared to other Leporids. Twenty-nine adults captured by Forys (1995) averaged 339.3 mm (SD 24.9 mm) in length from nose to tail and 1,224.1 g (SD 80.9 g) in mass.

Habitat and Life History

Marsh rabbits typically occupy wet areas with dense cover (Layne 1974). Forys (1995) and Forys et al. (1996) found LKMR in saltmarsh/buttonwood transition zones and freshwater marshes. On Boca Chica Key, Forys (1995) noted that LKMR used mid to high marsh more than intertidal marsh or buttonwood transitional. Historically, LKMR also have been found on coastal beach berms (USFWS 1999). In addition to wetland and coastal beach berm vegetation types, other subspecies of marsh rabbits have been known to use dry grassy fields; mangroves; hammocks; fallow tomato fields; and rank vegetation along canals, ditches, roadsides, and cultivated fields (Carr 1939, Schwartz 1952, Layne 1974). Within these habitats, marsh rabbits eat a wide variety of plants, including grasses, sedges, flowers, and the leaves and twigs of some woody species (Whitaker and Hamilton 1998). Forys (1999) found LKMR tended to feed on plant species according to their availability.

In general, rabbit habitat in the Lower Keys does not occur in large continuous areas. Instead, LKMRs exist as a metapopulation in small habitat patches scattered throughout the Lower Keys (Forys and Humphrey 1996). Adult rabbits establish permanent ranges within these patches, with same-sex ranges rarely overlapping (Forys and Humphrey 1996). Females may breed year-round and produce an average of 3.7 litters/year with 1–3 young/litter (Forys 1995). It is interesting to note that *S. p. paludicola* averaged 5.7 litters/year with 2–4 young/litter (Holler and Conaway 1979). Young remain in the thick grass nest for about 2 weeks (Forys 1995). Those that reach 8–10 months of age will often disperse to other habitat patches. Dispersal appears to be male biased (Forys 1995). On Boca Chica Key, Forys (1995) found dispersing rabbits were willing to cross airport runways, roads, and taxiways, but tended to use thick cover (Forys 1995). Rabbits were more likely to disperse through natural vegetation (i.e., buttonwoods, saltmarsh, hammocks, and mangrove) than disturbed areas, and individuals sometimes used strips of vegetation along roadways (Forys 1995).

Marsh rabbits probably live a maximum of 3–4 years in the wild (Whitaker and Hamilton 1998). Raptors appear to be one of the primary natural predators, which may explain why LKMRs are active primarily at night (Blair 1936). Chapman and Willner (1981) listed the northern harrier (*Circus cyaneus*) as one of the main predators of the species. A. Schuetz (Naval Air Facility, Key West [NAFKW], personal communication) noted that bald eagles (*Haliaeetus leucocephalus*) occasionally prey on LKMRs on Boca Chica Key. Other potential predators of adult LKMRs include eastern diamondback rattlesnakes (*Crotalus adamanteus*), feral and domestic cats, and dogs (Chapman and Willner 1981, Forys 1995). In addition to the above predators, raccoons (*Procyon lotor*), fire ants (*Solenopsis invicta*), and feral hogs (*Sus scrofa*) may prey on young rabbits (Howe 1988, Forys et al. 1996).

Status and Threats

According to a letter sent by E. Greene to Major E.A. Goldman of the Smithsonian Institution, rabbits were abundant on Boca Chica Key and other Lower Keys in 1942 (Lazell 1989). Over the last 20 years, however, more than half of the suitable marsh rabbit habitat in the Lower Keys has been lost to human development (USFWS 1999). Lazelle (1989) noted the extirpation of rabbits from entire islands, including the Torch Keys (Figure 2.15). In a1988 report to the USFWS, Howe asserted that the LKMR was in need of legal protection. Two years later, the USFWS listed the LKMR as an endangered species, citing the loss and fragmentation of the rabbit's habitat (USFWS 1990). Additional threats have included mortality from feral and domestic cats and vehicles; and degradation of habitat from trash dumping, off-road vehicles, mowing, and invasive exotic plant species (Forys 1995, USFWS 1999). Raccoons and fire ants may pose a threat to LKMRs as well (Forys et al. 1996). The USFWS (1999) estimated that approximately 100–300 adult LKMRs remained, and a population viability analysis (PVA) model suggested that the LKMR metapopulation had a 100% probability of being extinct in 50 years (Forys and Humphrey 1999).

STUDY OBJECTIVES

In 1996, the LKMR Recovery Team listed 4 priority actions to promote the subspecies' recovery: (1) land acquisition, (2) control of predation by cats, (3) monitoring of existing populations, and (4) reintroduction to suitable potential habitat (USFWS 1999). The objectives of my study were to address actions (3) and (4) and to provide management recommendations based on these actions. Monitoring the distribution of the species is critical for prioritizing and targeting other management actions, and reintroduction could reduce the probability of extinction for the species by increasing the number of occupied habitat patches.

CHAPTER II

DISTRIBUTION SURVEY

INTRODUCTION

Metapopulation Dynamics

A metapopulation can be defined as set of spatially discrete local populations that interact through dispersing individuals (Hanski and Gilpin 1991, McCullough 1996). The term "metapopulation" originated with Levins (1970), and though others had considered the topic of interacting local populations previously (Hanksi and Gilpin 1991), Levins (1969, 1970) quantified the concept through a model of the "classic" metapopulation. The key processes in the dynamics of a classic metapopulation are extinction and colonization (Hanksi and Gilipin 1991). Local populations are expected to become extinct through time, but the metapopulation will persist as long as the rate of extinction does not exceed the rate of colonization of empty patches (Levins 1969, 1970). Small metapopulations and those with greater isolation between patches are expected to be less likely to persist over time (Hanski 1991).

The classic metapopulation model of Levins (1969, 1970) is an oversimplification, as it ignores patch configuration and intra-patch dynamics (Hanski 1991). In the real world, the situation is much more complex, and most patch networks do not approximate the classic metapopulation (Harrison 1991). Even with this complexity, however, the key concepts of the Levins (1969, 1970) model (e.g., local extinction, colonization, discrete local populations) remain relevant for many species. In fact, metapopulation dynamics have become a key concept in conservation biology due to the loss and fragmentation of species' habitat (McCullough 1996).

The Lower Keys Marsh Rabbit Metapopulation

The case of the LKMR provides an example of the application of metapopulation concepts to conservation. Endemic to the Lower Keys of Florida, the LKMR exists as a metapopulation in patches of saltmarsh/buttonwood transition zone, freshwater wetlands, and coastal beach berm vegetation (Forys and Humphrey 1996). The LKMR was listed as federally endangered in 1990, primarily due to the loss and fragmentation of its habitat (USFWS 1990). It is thought that much of the subspecies' habitat was lost to human development from 1970–1996 (USFWS 1997). Distribution surveys that monitor the remaining patches of habitat are critical for assessing the health of the metapopulation and designing appropriate management strategies. In addition, knowledge of the spatial distribution of remaining local populations is also important, because the spatial context of habitat patches and the nature of the intervening matrix can have a profound impact on patterns of patch occupancy (Wiens 1996, Mazerolle and Villard 1999).

The first published survey of the LKMR metapopulation was conducted by Howe (1988), who surveyed 13 sites noted by J. Lazelle (unpublished data) and 3 additional patches. He reported that rabbits were absent from 4 of the original patches and the remaining patches were threatened by some degree of human development or encroachment.

Forys (1995) conducted a more comprehensive survey from 1991–1993, in which she identified 59 patches of potential LKMR habitat in the Lower Keys. This survey included all but 2 of the patches noted by Howe (1988). Nineteen of these patches were consistently occupied by LKMRs over the course of the study, and 23 others were occupied at least once over the 3 years. In 1995, Forys et al. (1996) discovered an additional 19 occupied patches and 47 patches of potential LKMR habitat. Historically, sign of LKMRs was observed on the Torch, Summerland, and Cudjoe keys (Howe 1988; Lazell 1989; D. Stevenson, Felix Environmental Services, personal communication). However, Forys (1995) and Forys et al. (1996) found no extant local populations between Big Pine and Sugarloaf keys (Fig. 1.16).

Under Forys (1995) and Forys et al. (1996)'s definition of a "patch," areas divided by major roads or separated by short distances of upland or mangrove vegetation were considered to be separate patches. This definition of a patch may provide an incomplete understanding of interactions within the LKMR metapopulation for 2 reasons. First, in a metapopulation, true "patches" represent local populations that interact only through dispersing individuals (Gilpin and Hanski 1991). Some of the patches designated by Forys (1995) and Forys et al. (1996) may be part of the same interacting local population. For instance, radio tracking data collected as part of a reintroduction program (Appendix A) indicated LKMRs will readily cross paved roads. In this thesis, a "patch" is defined as in Forys (1995) and Forys et al. (1996), and a group of interacting patches is termed a "local population."

Second, data on LKMR movements and habitat use are incomplete. The night movements of the LKMR have not been documented, and areas used irregularly or seasonally may not have been discovered in fecal pellet surveys. Radio tracking data collected as part of a reintroduction program (Appendix A) noted that LKMRs will use mangrove and occasionally upland vegetation types, though the frequency of use is unknown due to the lack of night observations. M. Barrett (University of South Florida, personal communication) and I have noticed fecal pellets in pinelands as well. Until the LKMR's movements can be better understood, it would be useful to develop a hypothesis to account for the uncertainty in LKMR habitat use and to better define local populations so the proper extent of habitat is protected and managed and so population studies and management actions take place at the correct scale.

Previous surveys did not delineate areas available for dispersing LKMRs. Given the significance of dispersal to metapopulations, it is important to identify potential dispersal areas. Forys (1995) found dispersers were more likely to use natural vegetation types (e.g., saltmarsh, hammock, and mangroves) than disturbed areas.

Study Objectives

The objectives of this study were (1) to update the current distribution and occupancy status of local LKMR populations and (2) to draw comparisons to past surveys. More specifically, these objectives included (a) surveying habitat patches documented in previous surveys, (b) locating additional patches of occupied and potential habitat, and (c) developing a hypothesis that both accounts for uncertainty in habitat use and movements and combines habitat patches into possible local populations.

METHODS

Patches

Rabbits are often cryptic and difficult to capture. Thus, fecal pellets commonly are used to study the distribution of rabbit species (e.g., Whitaker and Abrell 1986, Forys et al. 1996, Sugimura et al. 2000). Surveys for rabbit pellets provide the easiest and least time-consuming way to determine presence or absence of LKMRs (Forys et al. 1996) and therefore were used in my study. Patches of occupied and potential rabbit habitat were surveyed for pellets from May 2001–June 2003. Patches were searched systematically by walking informal transects throughout the patch. The following paragraphs describe the selection of sites for the surveys.

Published and Unpublished Surveys (1988–1995).-- The current survey incorporated known patches from several formal and informal surveys conducted from 1988–1995. Formal surveys included those by Howe (1988) and the more comprehensive surveys of Forys (1995) and Forys et al. (1996), which had been mapped in a geographic information system (GIS). P.A. Frank (Florida Keys National Wildlife Refuges, USFWS, unpublished data) added a patch on Water Key to this GIS map. Additional patches were included from informal surveys by A. Schuetz (NAFKW, personal communication) on Boca Chica Key, and a patch on No Name Key was surveyed based on a sighting by M. Folk (The Nature Conservancy, personal communication) in the late 1980s. Collectively, these surveys from the late 1980s through the mid 1990s will be referred to as "the previous surveys."

Notes on Blue-line Photographs.-- In 2003, P.A. Frank discovered blue-line aerial photographs of Big Pine Key with notes of rabbit and pellet sightings. The author of the notes, which were dated between 1968–1987, is unknown. A few of these areas had not been surveyed by Howe (1988) or Forys et al. (1996) but were added to my survey. Due to the older age of these sightings, they were considered separately from the previous surveys in the analyses.

New Patches.-- Attempts to identify new patches involved the use of several sources. First, the Advanced Identification of Wetlands (ADID) GIS coverage developed by the Florida Marine Research Institute (McGarry MacAulay et al. 1994) was used in conjunction with photo interpretation of digital orthophoto quarter quads (DOQQs). Surveys included many of the areas categorized as saltmarsh, freshwater marsh, freshwater hardwoods, and freshwater pine vegetation types on the ADID map. Second, P.A. Frank (USFWS, personal communication), R.R. Lopez (Texas A&M University, personal communication), and B. Hovanic (Monroe County Mosquito Control, personal communication) suggested areas of potential habitat. Third, reported sightings of LKMRs provided additional areas to search. Finally, further search options were gleaned from observations of form sites used by LKMRs tracked as part of a reintroduction program (Appendix A). Two LKMRs tracked on Boca Chica Key, for example, frequently used seasonally dry mangrove areas with a combination of white, black, and red mangrove species (Appendix A).

An effort was made to re-visit many of the patches, especially those on the major occupied keys: Big Pine, Sugarloaf, the Saddlebunch, and Boca Chica keys. Some patches were visited as many as 3 times during my study. Patches were listed as occupied if fecal pellets were found in $\geq$1 of these visits. This facilitated comparisons with Forys et al. (1996), who used the same method for assessing occupancy. The occupancy status of patches visited >1 time was classified as either "consistent" or "variable." I noted the presence or absence of both adult and juvenile fecal pellets, which can be distinguished from pellets of adults based on size (Forys 1995).

Data Collection.-- Data were recorded on printouts of 1994–1995 DOQQs and 1999 U. S. Geological Survey aerial photographs. DOQQs from 2001 were available for Boca Chica Key, courtesy of Ecology and Environment, Inc. (Miami Lakes, Florida, USA) and NAFKW. For consistency and easy comparison with the GIS maps of Forys et al. (1996), patch boundaries were delineated using the same method as Forys (1995), with areas divided by major roads, runways, or large bodies of water considered separate patches. Based on the mapping by Forys (1995) and Forys et al. (1996), it was assumed that a "major road" was paved and supported regular vehicular traffic. For example, Forys (1995) did not subdivide patch 38, which was bisected by a gravel road, or patch 35, which included a paved road that could not be accessed by automobiles. In the few occasions where Forys et al. (1996) did not follow these conventions, patches were subdivided to maintain consistency.

Data Analyses.-- Patch boundaries were digitized using ArcView (Version 3.2) Geographic Information System (Environmental Systems Research Institute, Redlands, California). Patch boundaries were drawn to include any areas with rabbit fecal pellets and adjacent areas of similar vegetation type and structure. Patch occupancy in my surveys was compared with the previous surveys and anonymous notes on blue line aerial photographs from 1968-1987. SPSS (Version 11.0; SPSS, Inc., Chicago, Illinois, USA) and Microsoft Excel (Version 2002; Microsoft Corporation, Seattle, Washington, USA) were used for all calculations and graphs.

Local Populations

Buffers were created around habitat patches: (1) to account for incomplete knowledge of rabbit movements and habitat use, and (2) to estimate which neighboring patches likely form an interacting local population. It was assumed that at least half of a rabbit's range likely falls within the constituent patches, as the distribution of pellets and day-time tracking data (Appendix A) suggested that these areas were used most often by LKMRs. Therefore, habitat patches were buffered by a distance equal to half the length of the mean range size of an LKMR. For simplicity, this distance was calculated as the radius of a circle with area equal to the mean range size. An individual's range was considered to include areas used by an individual for its normal daily activities, and 1-time, long-distance movements were excluded from the analyses (Burt 1943).

Data on range size was available from Forys (1995), who used the harmonic mean method (Dixon and Chapman 1980) to determine a mean range size of 3.96 ha for 23 adult LKMRs. The median of locations/rabbit was 88 (inter-quartile range 67–138, range 44–252) over a median of 7 months (inter-quartile range 5.5–11.5, range 3.5–21). However, the mean range value of 3.96 ha might be positively biased. The habitat patches where these animals were tracked ranged from 2.27– 4.86 ha (Forys et al. 1996), and Forys (1995) reported that the ranges of same-sex individuals rarely overlapped. Moreover, Forys (1995) reported that only 2 individuals ever crossed roads and that no rabbits ever crossed into neighboring patches. Trapping data in these patches suggested a mean density of 1.8 (SD 1.1) rabbits/ha (Forys and Humphrey 1997). A mean range size of 3.96 ha seems inconsistent with these observations. This inconsistency may be due to the use of the harmonic mean method, which is sensitive to grid cell size and spacing (Worton 1987). Unfortunately, Forys (1995) did not report the size and spacing used in her analyses. The harmonic mean method overestimated the size of simulated ranges developed by Seaman and Powell (1996), and the authors suggested the harmonic mean method was an inappropriate estimator of range size.

Given the uncertainty about bias in past data, a mean range was calculated using radio tracking data obtained from a control group studied as part of a LKMR reintroduction (Chapter III). Range size was calculated for rabbits that were tracked ≥30 times over the course of ≥5 months. All radio locations were taken ≥12 hours apart, and with the exception of a few nighttime locations, all points were collected during daylight hours. Range size was calculated using a modified minimum convex polygon (MCP), with bodies of water and inaccessible areas removed (Mohr 1947, White and Garrott 1990:153). The Animal Movement Program (version 2.0) was used to construct the MCPs in ArcView 3.2 (Hooge et al. 1999).The MCP suffers from several problems, most notably its sensitivity to sample size (Worton 1987, White and Garrott 1990:148). The kernel method is a common probabilistic alternative to the MCP, and has been recommended for the estimation of animal ranges (Worton 1989, Seaman and Powell 1996, Powell 2000). However, unequal tracking effort (i.e., rabbits were tracked more frequently early in the study) might create bias in the kernel estimates. Because nearly all tracking took place during the day, kernel estimates might only include areas directly around form sites rather than including the areas traveled between form sites. Therefore, the MCP was chosen instead of kernel methods.

Once the buffer distance was determined, buffers were created around patches using ArcView (Version 3.2). Patches that had been destroyed by human development or otherwise rendered unsuitable for rabbits since previous surveys were excluded from these analyses. Human development and large bodies of water were clipped from the buffers. Patches with overlapping buffers or with buffers <2-m apart were considered to be part of the same occupied or potential local population (OPLP). Each OPLP was given an identification number equal to the lowest identification number of its constituent patches. The occupancy status of OPLPs was compared with previous surveys. Roads and scarified sites were clipped from the area of each OPLP to determine the total usable habitat for LKMRs.

Dispersal Habitat

A buffer of 2,050 m (the longest dispersal distance observed by Forys [1995]) was placed around OPLPs using the Cost Distance Grid Tools extension for ArcView (Version 3.2). Unlike buffers using Euclidean distance, a cost distance grid takes into account barriers that would make animal movements deviate from a straight-line (e.g., canals, large bodies of water). It was assumed human development does not act as a barrier to dispersal. The ADID data was used to identify all areas of native vegetation falling within 2,050m of OPLPs, resulting in a map of potential dispersal habitat.

RESULTS

Patches

Published and Unpublished Surveys (1988–1995).-- Current mapping resulted in a change in size and shape for some patches of habitat from previous surveys (Figs. 2.1–2.14). The borders of some occupied patches were expanded to include adjacent habitat where pellets were present. Some patches considered separate in previous surveys were combined into 1 patch. In other cases, occupied patches were either reduced in size or split into multiple patches. This was due to more conservative mapping in which only areas with pellets and adjacent similar habitat were included. Thus, some vegetation types that rarely had pellets were generally excluded from the mapping of patches unless evidence of their use could be found. For instance, extensive areas of intertidal marsh, open understory black mangrove forests, dwarf mangrove mudflats, and closed-canopy hammocks were often excluded. For consistency, these vegetation types also were removed from the mapping of potential habitat. Overall, these changes in mapping resulted in an increase in area from 568.5 ha to 661.2 ha for patches identified in previous surveys and a net increase in the number of patches from 137 to 142. Eight of the 142 patches were not surveyed during my study (Table 2.1).

Since the previous surveys, there has been a net decrease of 9 in the number of occupied patches (Table 2.2, Figs. 2.1–2.14). Two of these patches, patches 113 and 131, have been rendered unsuitable for rabbits due to mowing and construction activities, respectively. Although listed as occupied, patch 31 on Sugarloaf Key was mowed by the landowner a few months after the survey. Big Pine Key exhibited the greatest net loss (Table 2.2), and none of the patches south of U. S. Highway 1 on this key were found to be occupied during my study (Fig. 2.12). Three of the extirpated patches were on small outer islands (Table 2.2, Figs. 2.1, 2.5, 2.6, 2.8, 2.12. 2.13). The only island with a net gain in patch occupancy was Sugarloaf Key (Table 2.2). Of the 19 consistently-occupied patches observed by Forys et al. (1996), 4 exhibited no sign of rabbits over the course of my study (Table 2.3). None of the consistently unoccupied patches documented by Forys et al. (1996) were colonized during my surveys.

Notes on Blue-line Photographs.-- The blue-line photographs contained 20 sites with either fecal pellets or sightings of individuals (Fig. 2.15). Five of these areas occurred outside of patches included in the previous surveys (Figs. 2.5, 2.15). Three of these 5 were included as potential habitat in the current distribution map (Fig. 2.15). The remaining 2 sightings occurred in areas that no longer appear to be suitable for LKMRs (Fig. 2.15).

New Patches.--. This survey discovered forty patches of occupied LKMR habitat that had not been documented in the previous surveys (Figs. 2.16–2.21). These new patches totaled 88.7 ha and were spread throughout the Lower Keys, though most were found on Big Pine Key and Boca Chica Key (Table 2.4). Nearly half of the land area of new occupied patches was on Big Pine Key (Table 2.4). Forty-six patches (64.0 ha) considered to be potential LKMR habitat also were found during my survey (Table 2.5).

Some of the new occupied patches included vegetation features that differed from the common habitat features described by Forys (1995). On Boca Chica Key, LKMRs were found in disturbed areas dominated by wire bluestem (*Schizachyrium gracile*) and lead tree (*Leucaena leucocephala*). The rabbits appeared to seek cover in clumps of lead tree and to forage in the grasses along the periphery of these clumps. Fecal pellets also were discovered in mangroves, especially in areas with closely-spaced white and black mangroves that were seasonally dry. Fecal pellets also were discovered in marshes dominated by gulf coast spike rush (*Eleocharis cellulosa*). In one of these marshes, narrow paths through the gulf coast spike rush could be seen clearly. These paths usually ran between small, shrubby clusters of buttonwoods or mangroves. Pellets could often be found at the base of the trees, where the ground was slightly elevated. On Big Pine Key, LKMR pellets were discovered in pinelands adjacent to freshwater pine and freshwater marsh areas. Rabbits also were seen foraging on lawns at the edge of mangroves at the headquarters of the Florida Keys National Wildlife Refuges. On Howe Key, rabbit pellets were found along the edge of hammock in a narrow buttonwood transitional area.

Summary of habitat Patches.-- Combining the patches known from the previous surveys with the new patches discovered during my study resulted in 228 patches covering 814.0 ha (Figs. 2.10, 2.22–2.27, Appendix B). The distribution of patch size, which ranged from 0.1 ha to 51.0 ha, was positively skewed (Fig. 2.28). The median patch size was 1.8 ha, with an inter-quartile range of 0.7–4.2 ha.

One hundred and two patches, totaling 522.6 ha of habitat, were occupied by LKMRs (Table 2.6). Juvenile pellets were found at least once in 43 of the 102 patches. Ninety percent of occupied patches and 88% of the total occupied land area were found on Big Pine, Sugarloaf, the Saddlebunch, and Boca Chica keys. Big Pine Key and Boca Chica Key together contained 61% of all occupied patches and 68% of the total occupied land area (Table 2.6). Eighty-two of the occupied patches were surveyed more than once (68 surveyed twice, 14 surveyed 3 times), and 66 of these were consistently occupied (Figs. 2.29–2.33, Appendix B). The median size of occupied patches was 2.4 ha, with an inter-quartile range of 0.7–5.1 ha.

Table 2.1 Patches not visited during Lower Keys marsh rabbit distribution surveys from 2001—2003 in the Lower Keys of Florida, USA.

Patch	Key	Occupied in1995?	Reason for not surveying
75	Ramrod	No	Access restricted; could not get permission from landowner
77	Ramrod	No	Access restricted; could not get permission from landowner
78	Big Torch	No	Multiple private owners; patch unlikely to have been colonized
91	Snipe Point	No	Virtually no probability of colonization; too isolated
97	Mud	No	Virtually no probability of colonization; too isolated
98	Marvin	No	Virtually no probability of colonization; too isolated
100	Hopkins	No	Access restricted; could not get permission from new landowner
101	Cook	No	Multiple private owners; patch unlikely to have been colonized

Table 2.2. Change in the number of patches occupied by Lower Keys marsh rabbits in 2001–2003 surveys and 1988–1995 surveys in the Lower Keys of Florida, USA, considering only the 142 patches visited from 1988–1995.

Key	Occupied 2001–2003	Occupied 1988–1995	Extirpated patches since 1995	Colonized patches since 1995	Net change since 1995
Annette	1	1	0	0	0
Big Munson	0	1	1	0	-1
Big Pine	12	17	9	4	-5
Boca Chica	22	23	3	2	-1
East Rockland	2	2	0	0	0
Geiger	2	4	2	0	-2
Mayo	2	2	0	0	0
No Name	1	1	1	1	0
Porpoise	0	1	1	0	-1
Saddlebunch	8	10	2	0	-2
Saddlehill	0	1	1	0	-1
Sugarloaf	12	8	1	5	4
Total	62	71	21	12	-9

Table 2.3. Occupancy status in 2001–2003 of patches of Lower Keys marsh rabbit habitat that were consistently occupied in surveys from 1991–1995 (Forys 1995, Forys et al. 1996).

Patch	Key	Occupied?	Area (ha)
1	East Rockland	yes	2.6
2	East Rockland	yes	0.9
4	Boca Chica	no	1.7
7	Boca Chica	yes	1.6
8	Boca Chica	yes	4.3
9	Boca Chica	yes	6.3
10	Geiger	yes	0.4
11	Geiger	no	1.0
12	Boca Chica	yes	1.3
13	Geiger	no	3.7
14	Boca Chica	yes	1.4
15	Boca Chica	yes	2.5
25	Boca Chica	yes	1.7
30	Saddlebunch	yes	1.8
31	Sugarloaf	yes	5.0
32	Sugarloaf	yes	10.0
33	Sugarloaf	yes	21.5
53	Big Pine	yes	44.0
57	Big Pine	no	0.3

Table 2.4. Number and area (ha) of patches of occupied Lower Keys marsh rabbit habitat identified during the 2001–2003 distribution survey in the Lower Keys of Florida, USA.

Key	Number of patches	Area (ha)
Big Pine	14	41.4
Boca Chica	14	18.2
Howe	2	19.1
Sugarloaf	3	1.7
Saddlebunch	7	8.3
Total	40	88.7

Table 2.5. Number and area (ha) of new patches of potential Lower Keys marsh rabbit habitat identified during the 2001–2003 distribution survey in the Lower Keys of Florida, USA.

Key	Number of patches	Area (ha)
Big Pine	5	15.2
Big Torch	4	10.6
Cudjoe	17	12.6
East Water	1	0.9
Geiger	2	0.3
Little Pine	3	2.6
Little Torch	5	11.2
Sugarloaf	2	1.2
Middle Torch	1	0.6
N. Johnson	1	5.1
Saddlebunch	4	3.4
Summerland	1	0.4
Total	44	62.2

Table 2.6. Number and area (ha) of occupied Lower Keys marsh rabbit habitat patches documented during the 2001–2003 distribution survey in the Lower Keys of Florida, USA.

Key	Number of patches	% of total number	Area (ha)	% of total area
Annette	1	1.0	23.6	4.5
Big Pine	26	25.5	244.8	46.8
Boca Chica	36	35.3	111.9	21.4
East Rockland	2	2.0	3.5	0.7
Geiger	2	2.0	1.5	0.3
Howe	2	2.0	19.1	3.7
Sugarloaf	15	14.7	73.9	14.1
Mayo	2	2.0	9.4	1.8
No Name	1	1.0	1.7	0.3
Saddlebunch	15	14.7	33.2	6.4
Total	102	100.0	522.6	100.0

Table 2.7. Number and area (ha) of potential Lower Keys marsh rabbit habitat patches documented during the 2001–2003 distribution survey in the Lower Keys of Florida, USA.

Key	Number of patches	% of total number	Area (ha)	% of area
Big Johnson	2	1.7	3.9	1.4
Big Munson	1	0.8	9.8	3.5
Big Pine	16	13.6	39.3	14.1
Big Torch	12	10.2	47.3	17.0
Boca Chica	6	5.1	12.9	4.6
Cudjoe	24	20.3	32.6	11.7
East Water	1	0.8	0.9	0.3
Geiger	4	3.4	5.0	1.8
Little Pine	4	3.4	13.1	4.7
Little Torch	6	5.1	16.6	6.0
Lower Sugarloaf	13	11.0	33.8	12.2
Middle Torch	4	3.4	9.7	3.5
N. Johnson	2	1.7	6.6	2.4
No Name	2	1.7	3.6	1.3
Porpoise	1	0.8	2.4	0.9
Ramrod	2	1.7	5.0	1.8
Saddlebunch	8	8.5	3.4	1.2
Saddlehill	1	0.8	2.4	0.9
Summerland	6	5.1	21.7	7.8
Water	3	2.5	4.2	1.5
Total	118	100.0	277.9	100.0

Table 2.8. One-hundred-percent modified-minimum-convex-polygon (MCP) ranges for 9 Lower Keys marsh rabbits tracked for $\geq$5 months from 2001–2003 in the Lower Keys of Florida, USA. The population to which each rabbit belonged and the sex and age of each individual are presented.

Rabbit identification number	Number of locations	Population	Key	Tracking period (days)	Sex	Age	MCP (ha)
422554031C	88	3	Boca Chica	358	Female	Adult	0.4
42257C2666	64	3	Boca Chica	157	Male	Adult	0.5
4225523E75	76	8	Boca Chica	210	Male	Adult	2.1
4225635412	69	8	Boca Chica	167	Female	Adult	0.6
4225716E16	65	8	Boca Chica	151	Male	Subadult	0.6
42257D217F	79	8	Boca Chica	285	Male	Adult	2.0
422873767B	98	8	Boca Chica	354	Male	Adult	1.8
42254C2F78	53	33	Sugarloaf	294	Male	Adult	0.6
422F31447B	33	162	Saddlebunch	163	Male	Adult	1.8

Table 2.9. Change in the number of Lower Keys marsh rabbit populations in 2001–2003 surveys and 1988–1995 surveys in the Lower Keys of Florida, USA, considering only the populations visited in the 1988–1995 surveys.

Key	Occupied 2001-2003	Occupied 1988-1995	Extirpated since 1995	Colonized since 1995	Net change since 1995
Annette	1	1	0	0	0
Big Munson	0	1	1	0	-1
Big Pine	5	10	6	1	-5
Boca Chica	15	15	2	2	0
East Rockland	1	1	0	0	0
Geiger	2	3	1	0	-1
Mayo	1	1	0	0	0
No Name	1	1	1	1	0
Porpoise	0	1	1	0	-1
Saddlebunch	6	7	1	0	-1
Saddlehill	0	1	1	0	-1
Sugarloaf	12	10	1	3	2
Total	44	52	15	7	-8

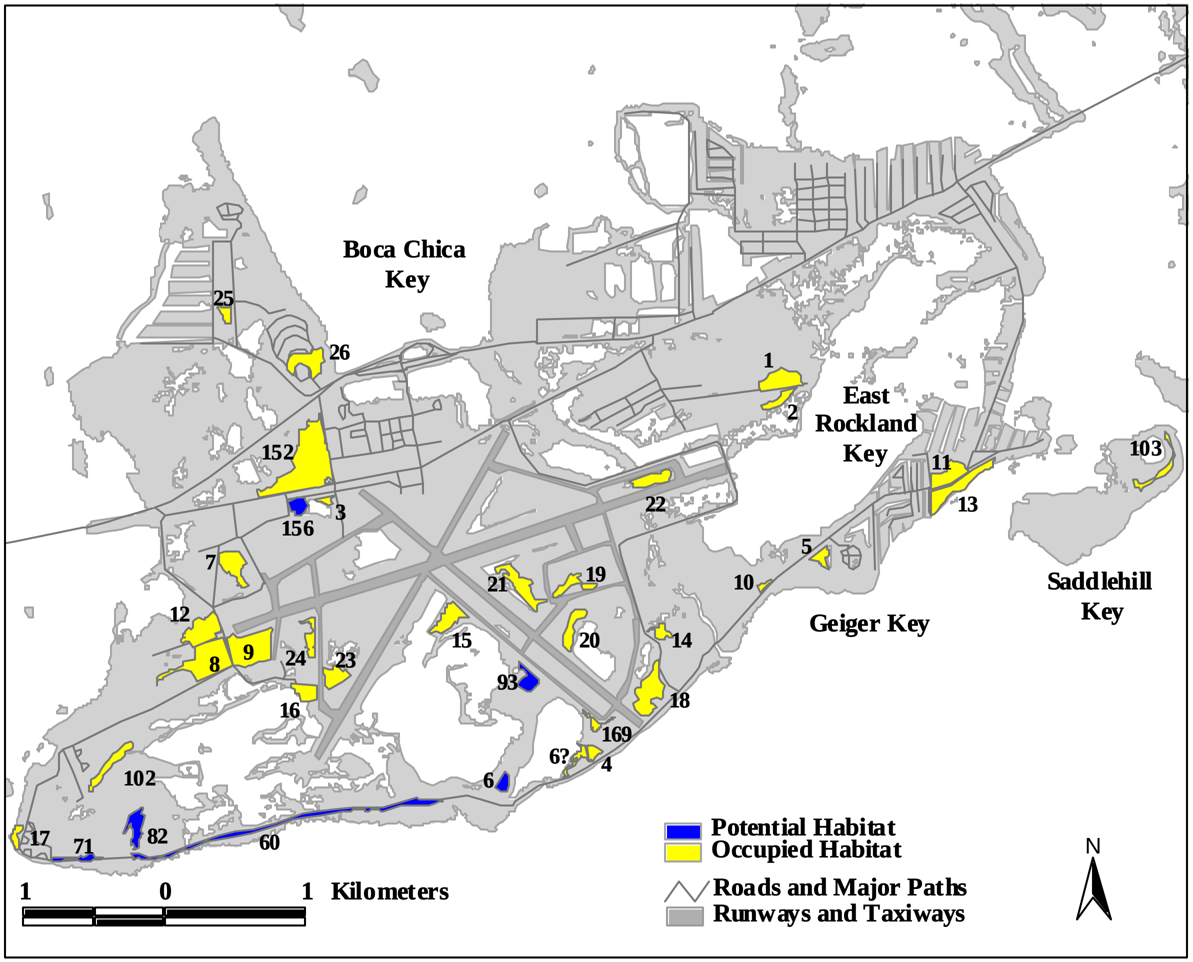

Fig. 2.1. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Boca Chica, East Rockland, Geiger, and Saddlehill keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

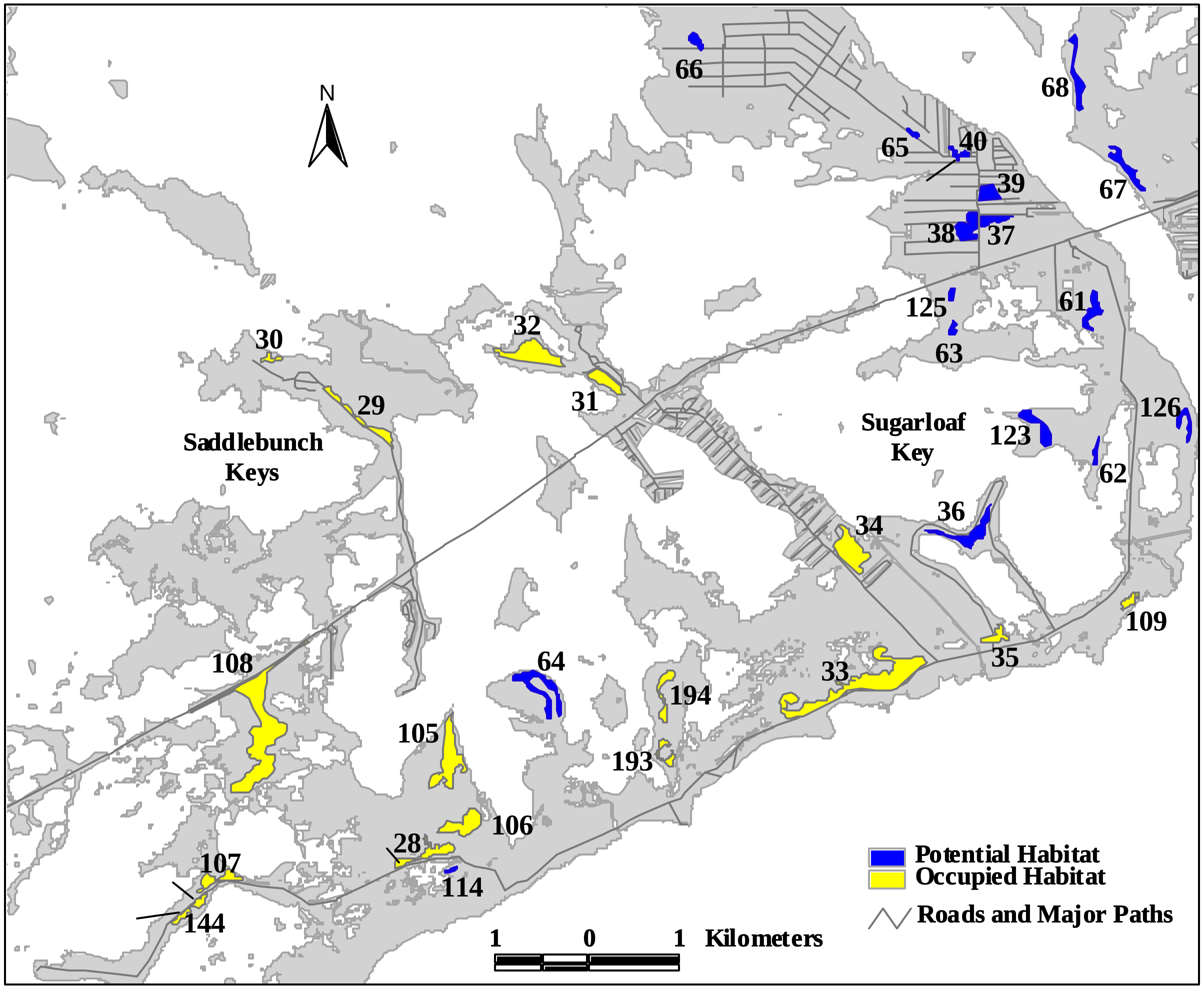

Fig. 2.2. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Sugarloaf and the Saddlebunch keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

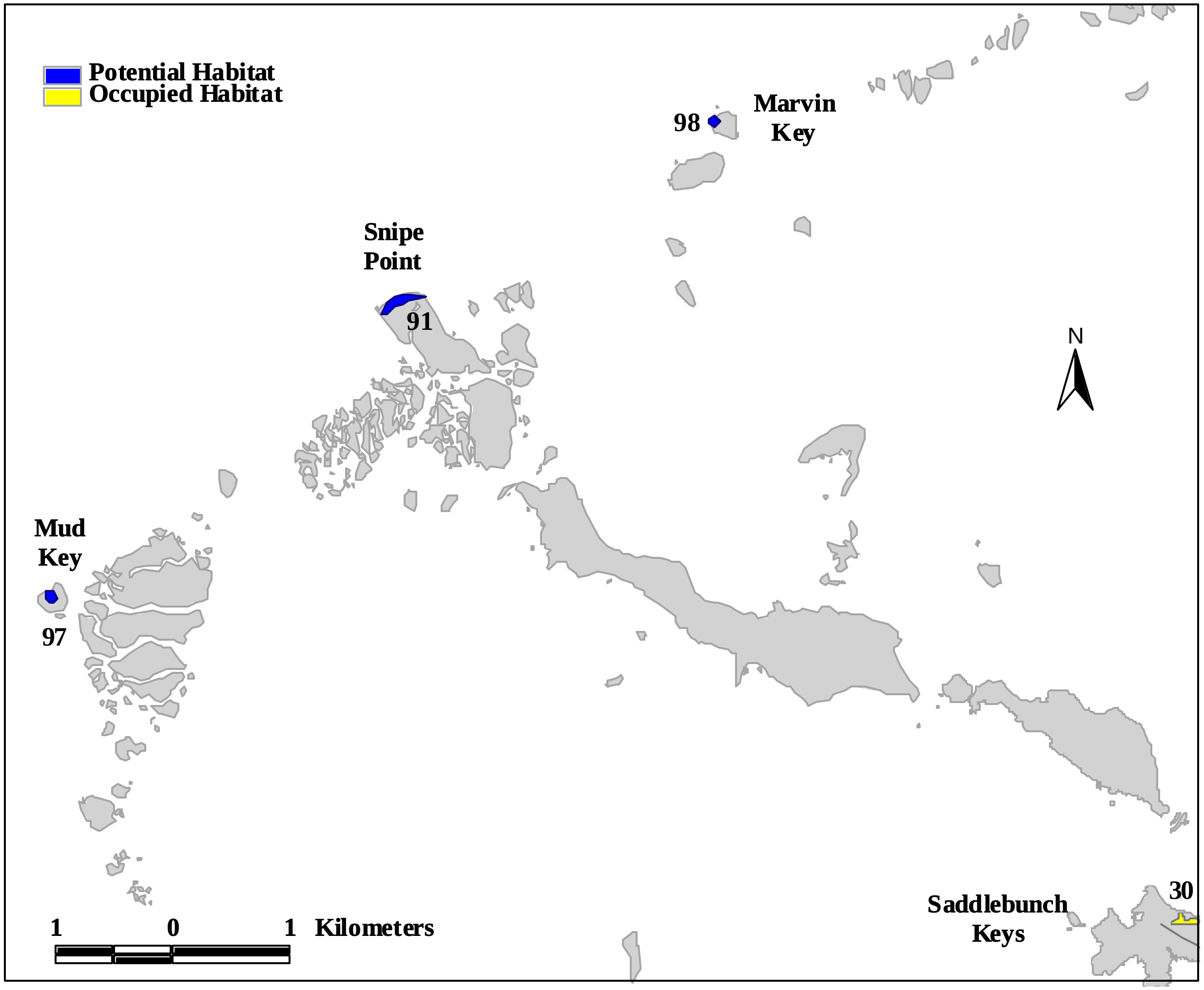

Fig. 2.3. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Mud, Snipe Point, and Marvin keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

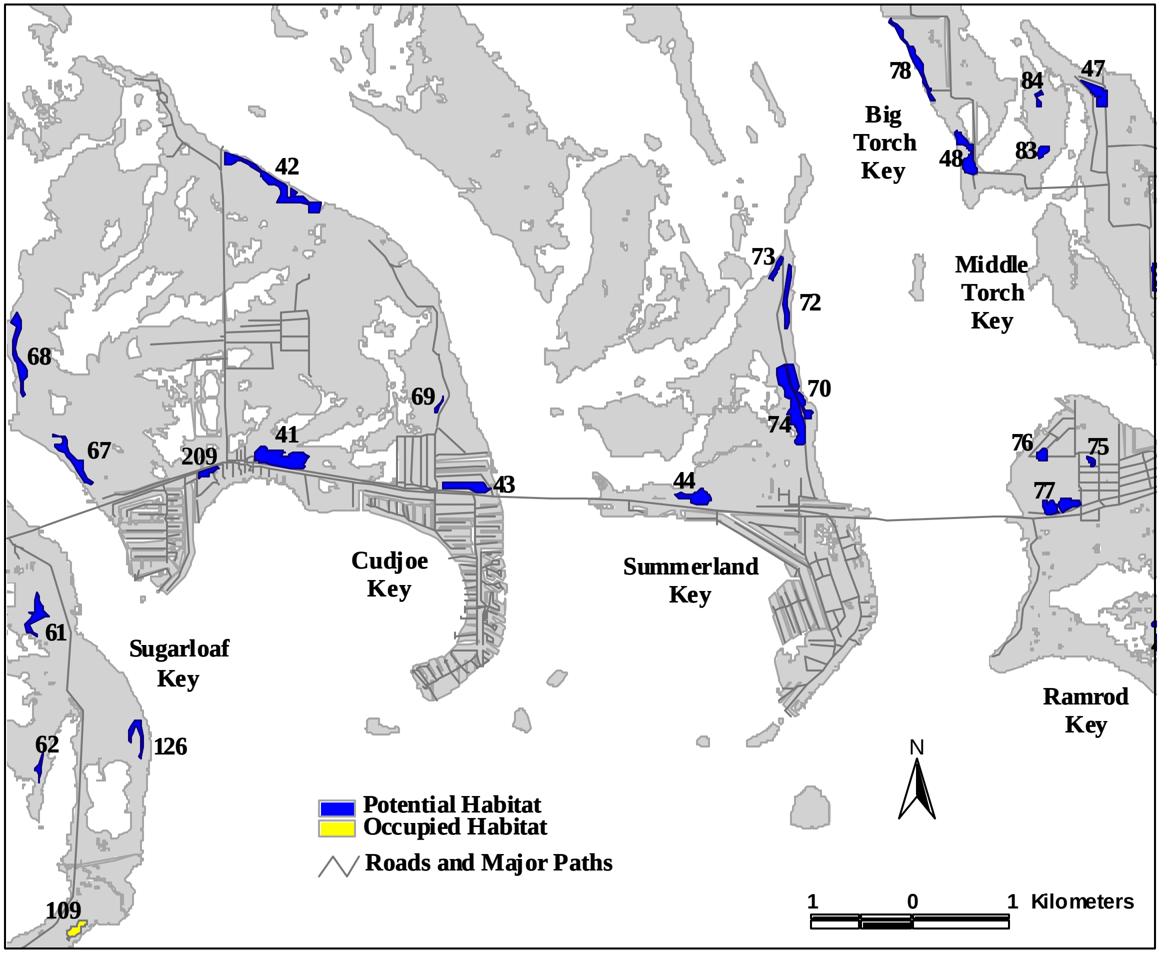

Fig. 2.4. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

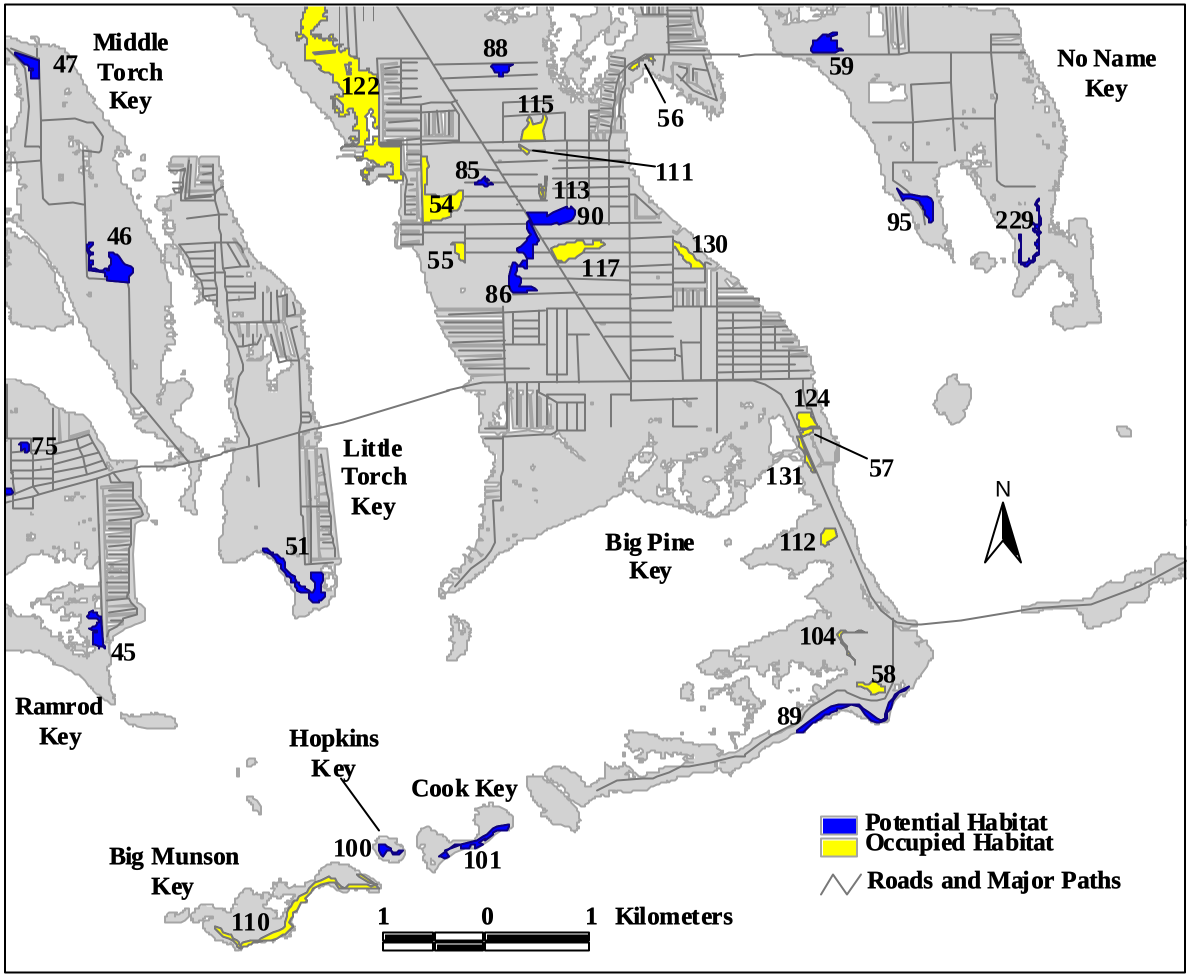

Fig. 2.5. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Middle Torch, Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Ramrod and Big Pine keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

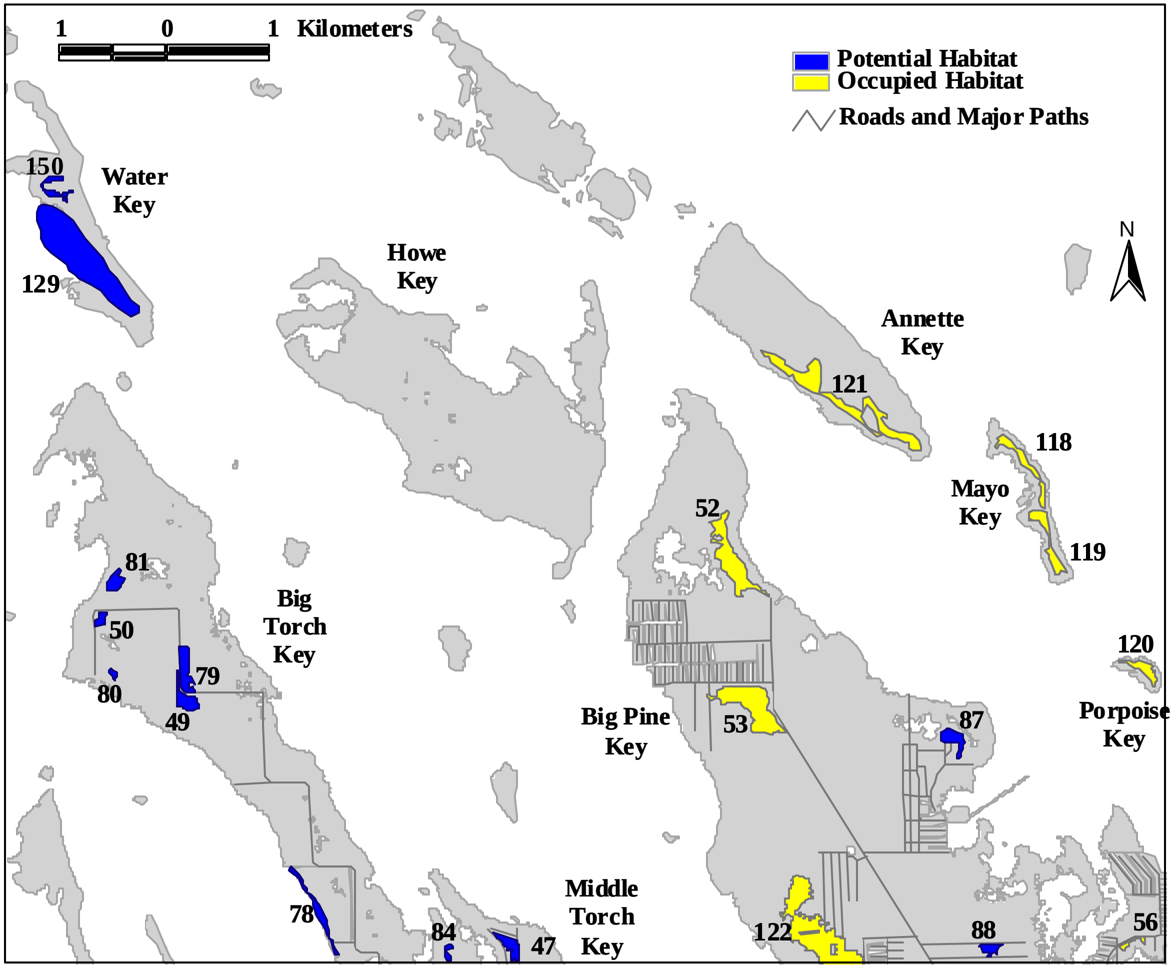

Fig. 2.6. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Big Torch, Water, Annette, Mayo, and Porpoise keys and portions of Middle Torch and Big Pine keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in $\geq$1 survey during this period.

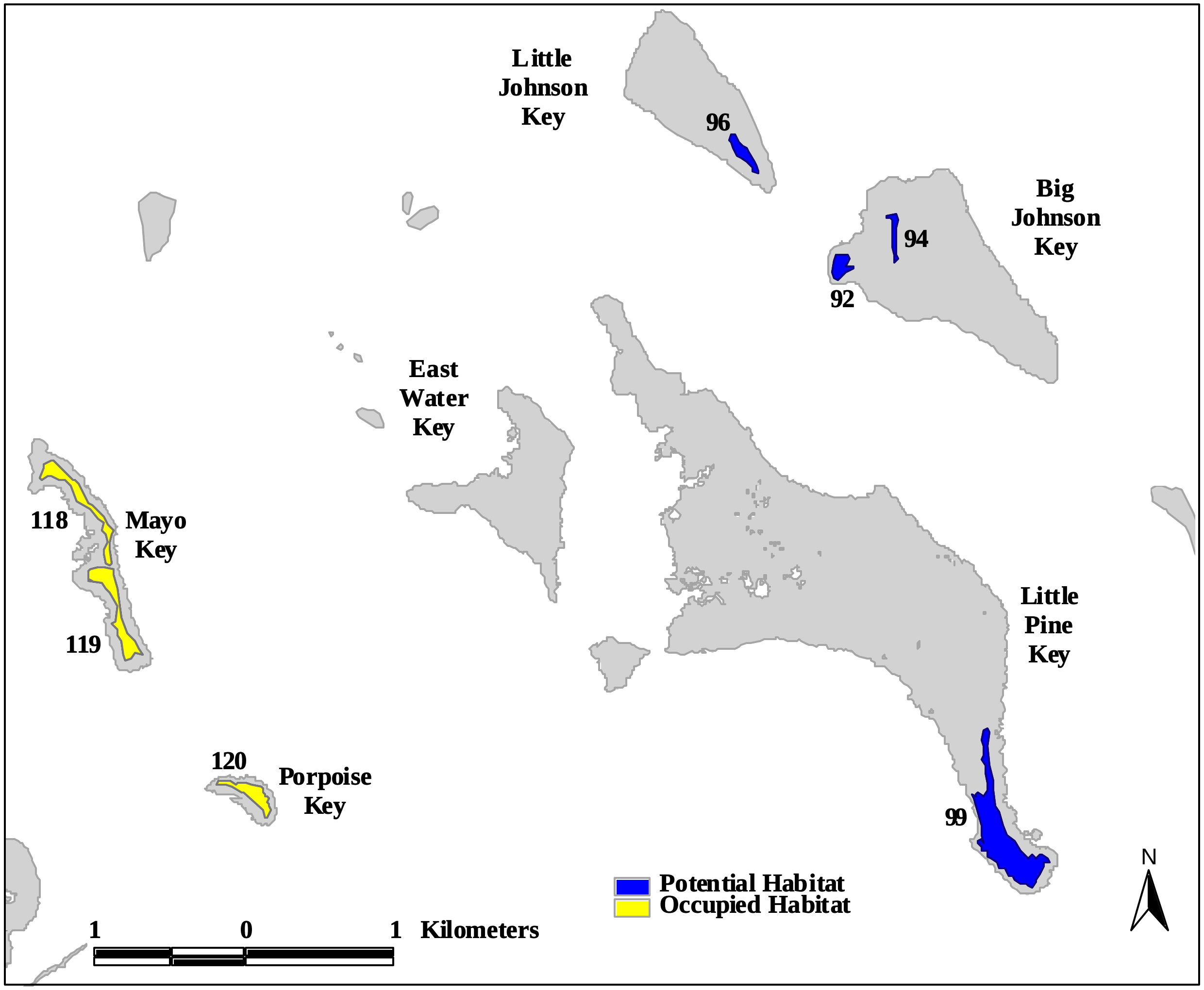

Fig. 2.7. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Mayo, Porpoise, Little Pine, and the Johnson keys in formal and informal surveys conducted 1988–1995 (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

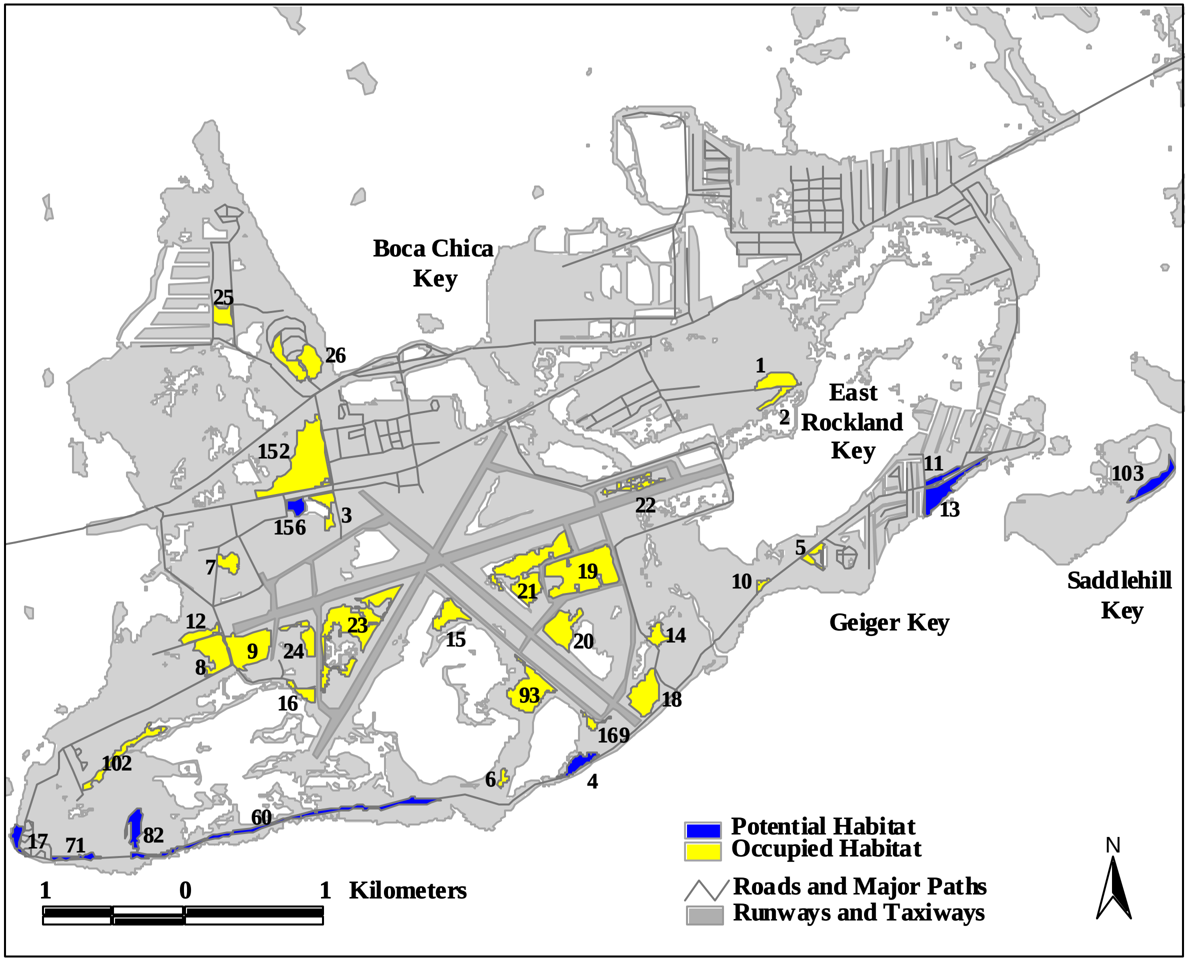

Fig. 2.8. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Boca Chica, East Rockland, Geiger, and Saddlehill keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

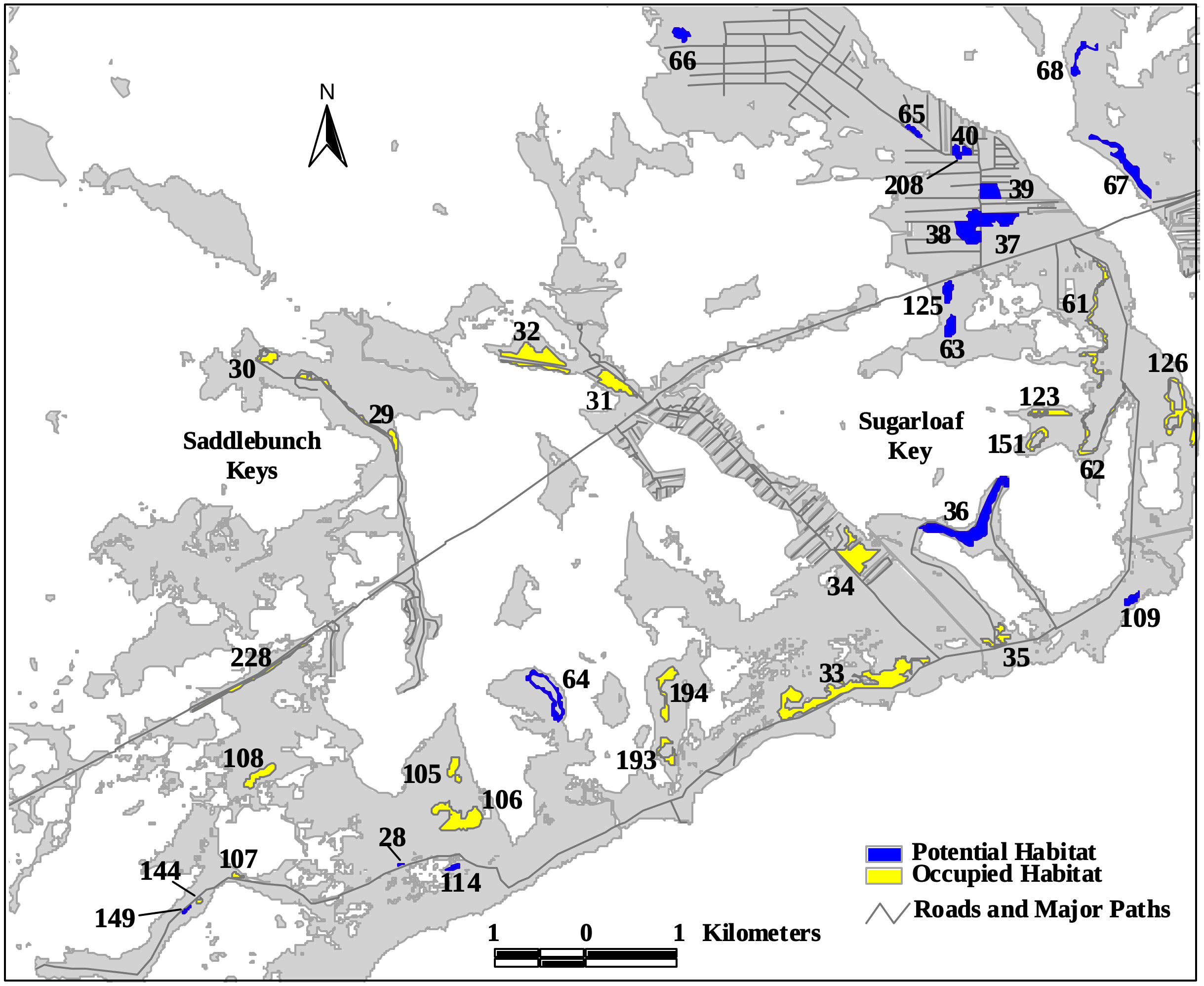

Fig. 2.9. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Sugarloaf and the Saddlebunch keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

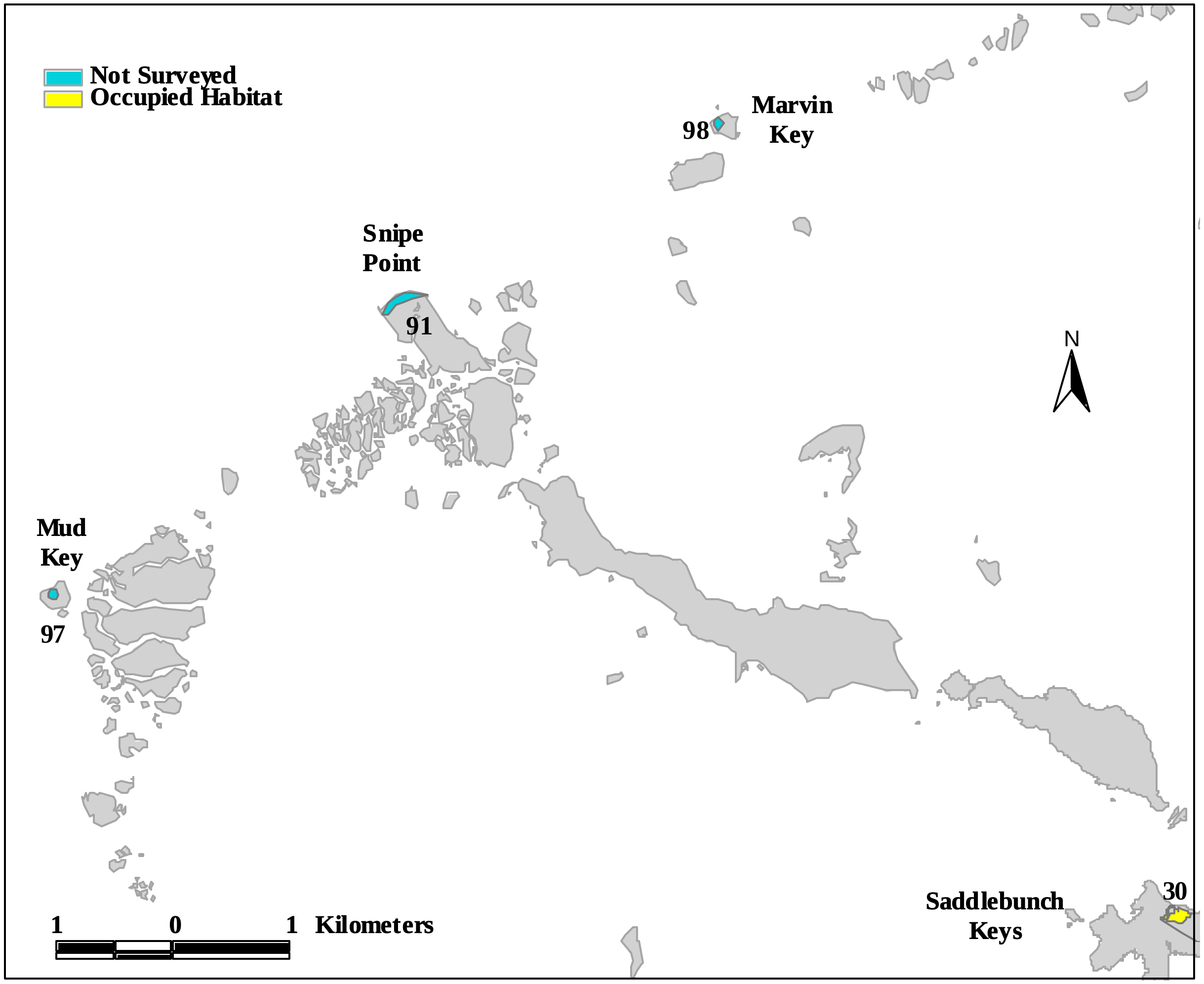

Fig. 2.10. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Mud, Snipe Point, and Marvin keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

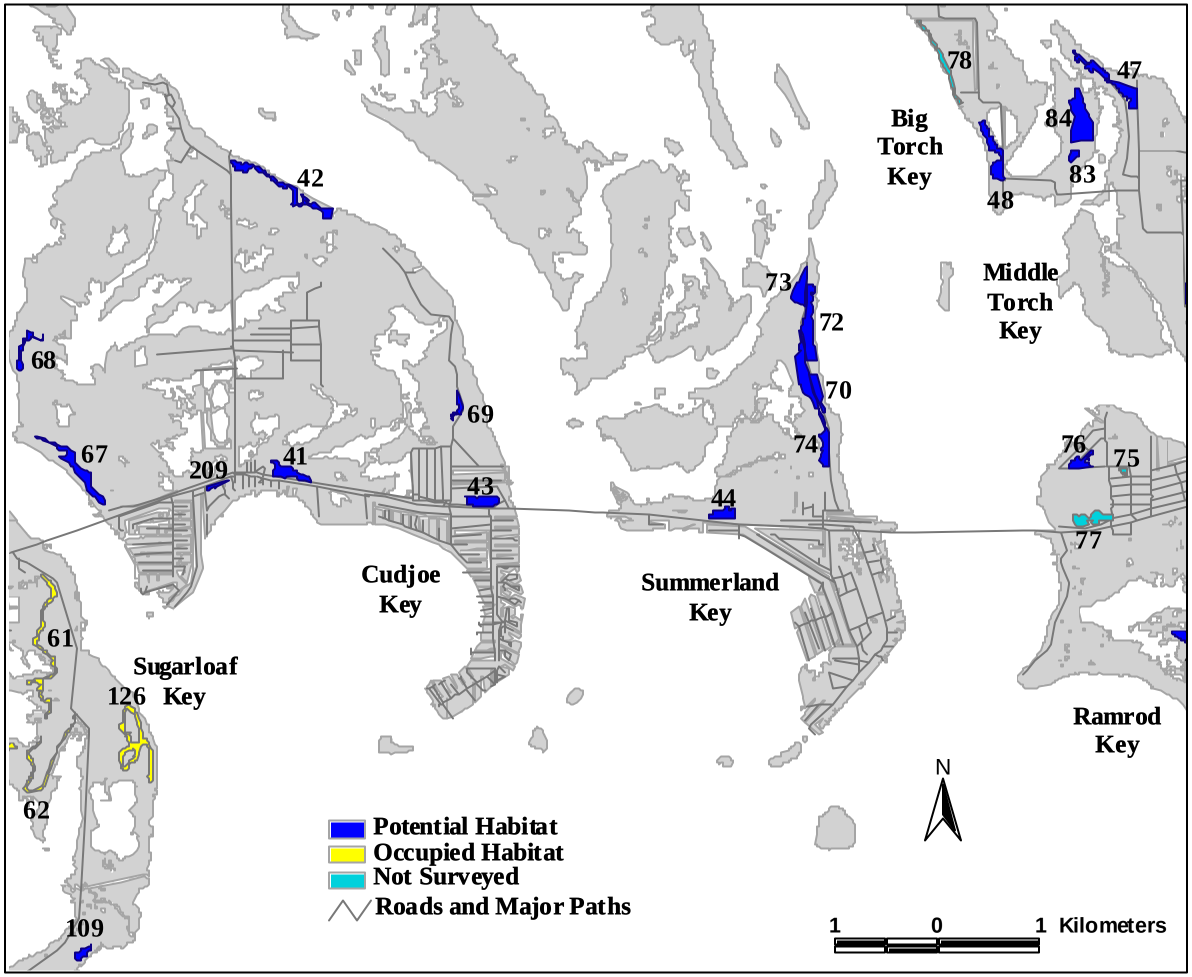

Fig. 2.11. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

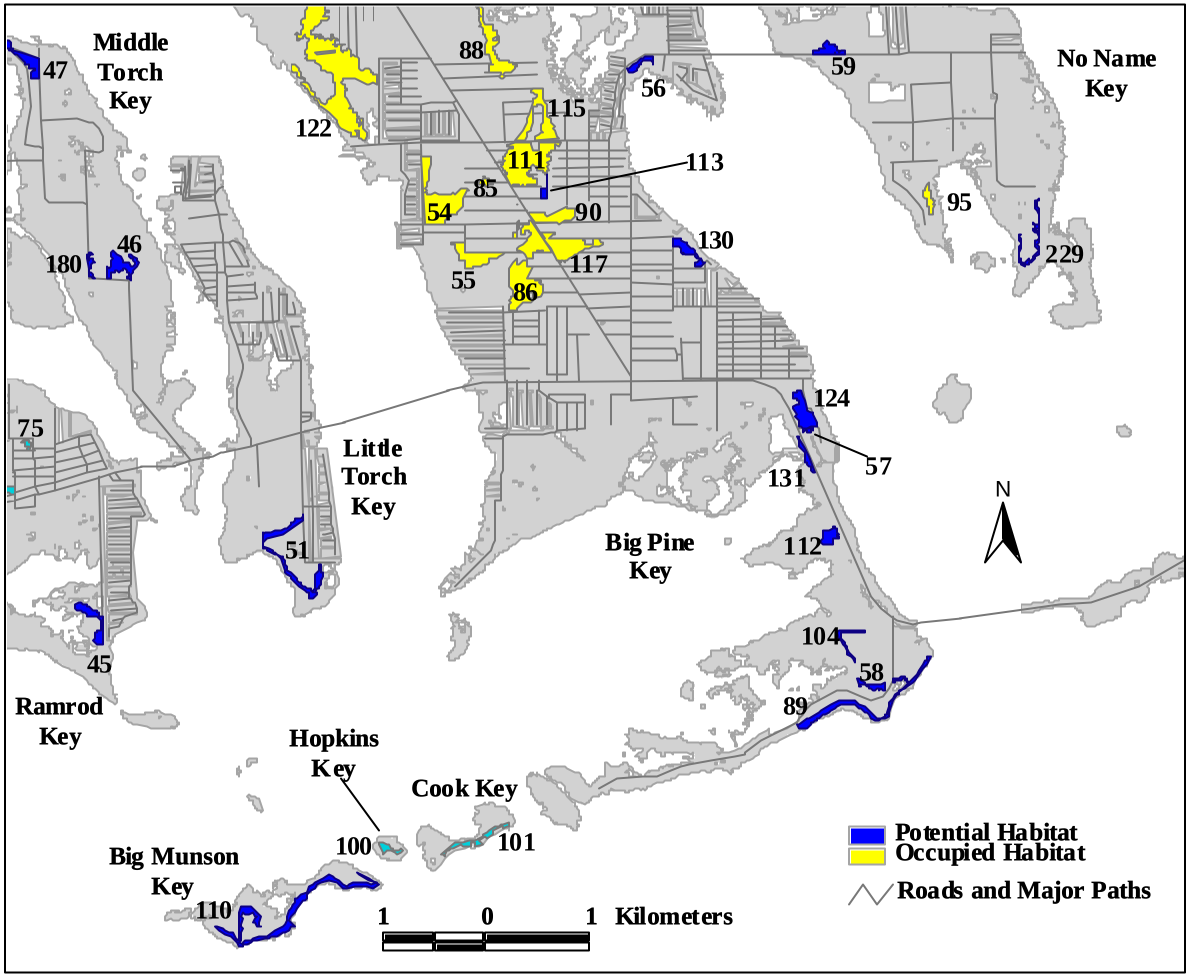

Fig. 2.12. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Middle Torch, Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Ramrod and Big Pine keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

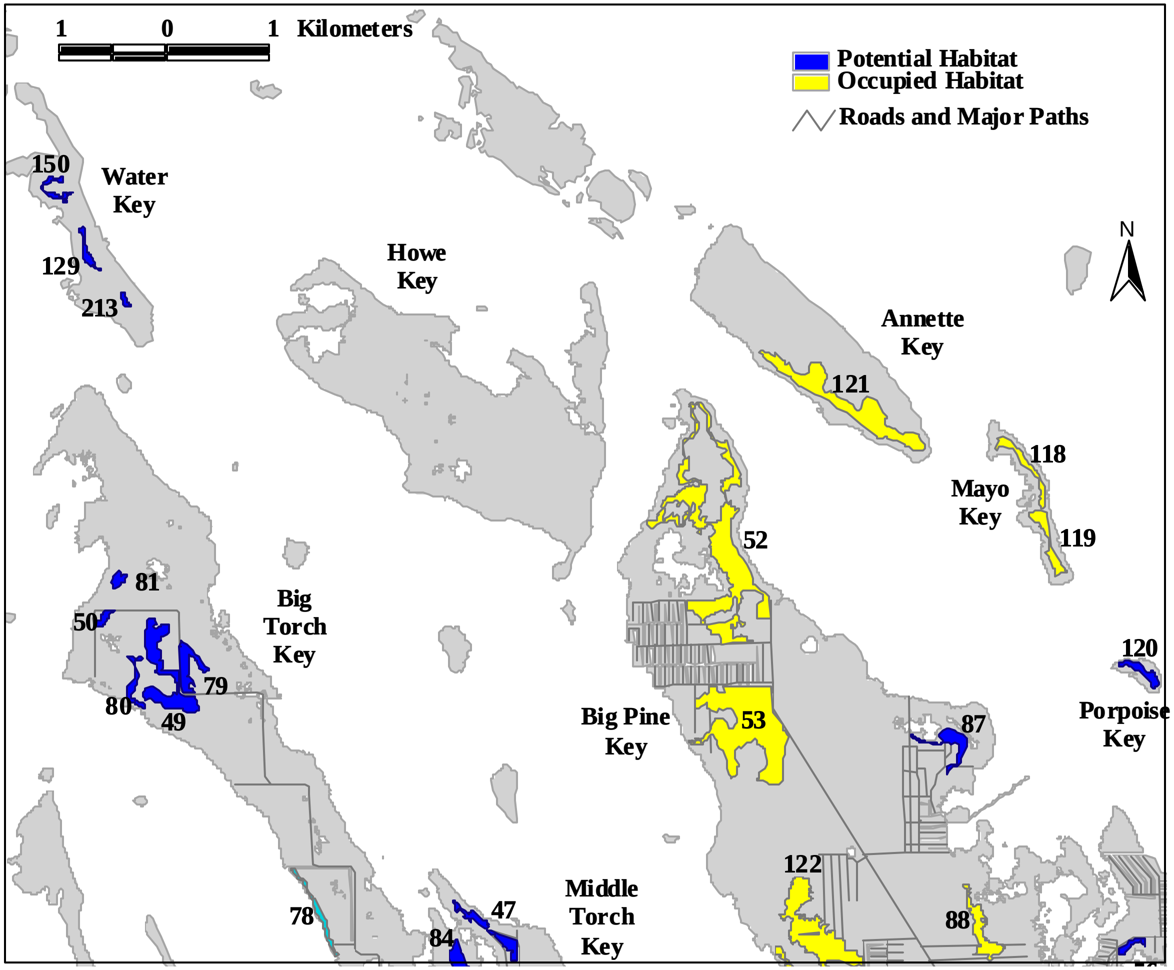

Fig. 2.13. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Big Torch, Water, Annette, Mayo, and Porpoise keys and portions of Middle Torch and Big Pine keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

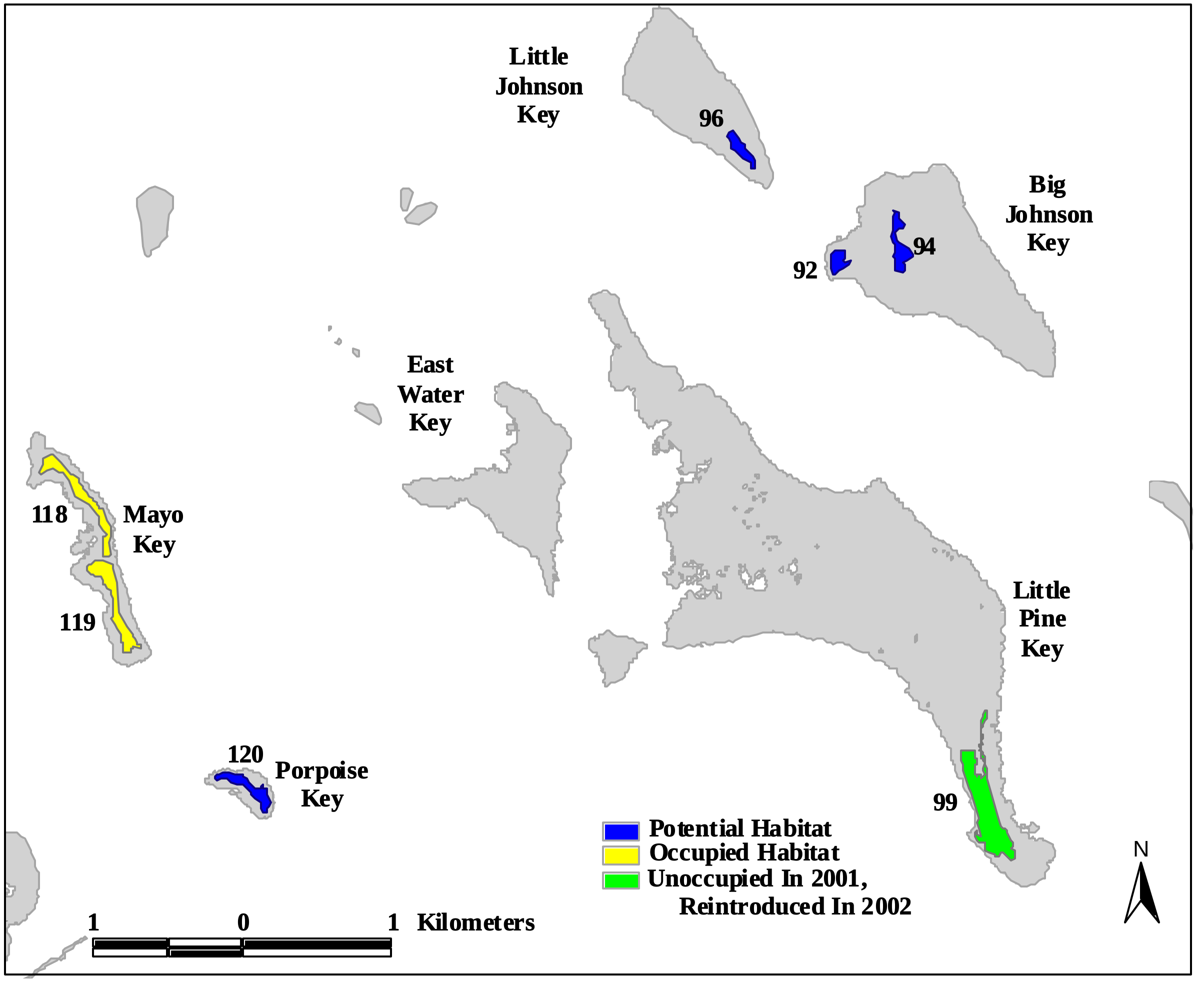

Fig. 2.14. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Mayo, Porpoise, Little Pine, and the Johnson keys in 2001–2003, considering only patches known from previous (1988–1995) surveys (Howe 1988, Forys 1995, Forys et al. 1996). A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

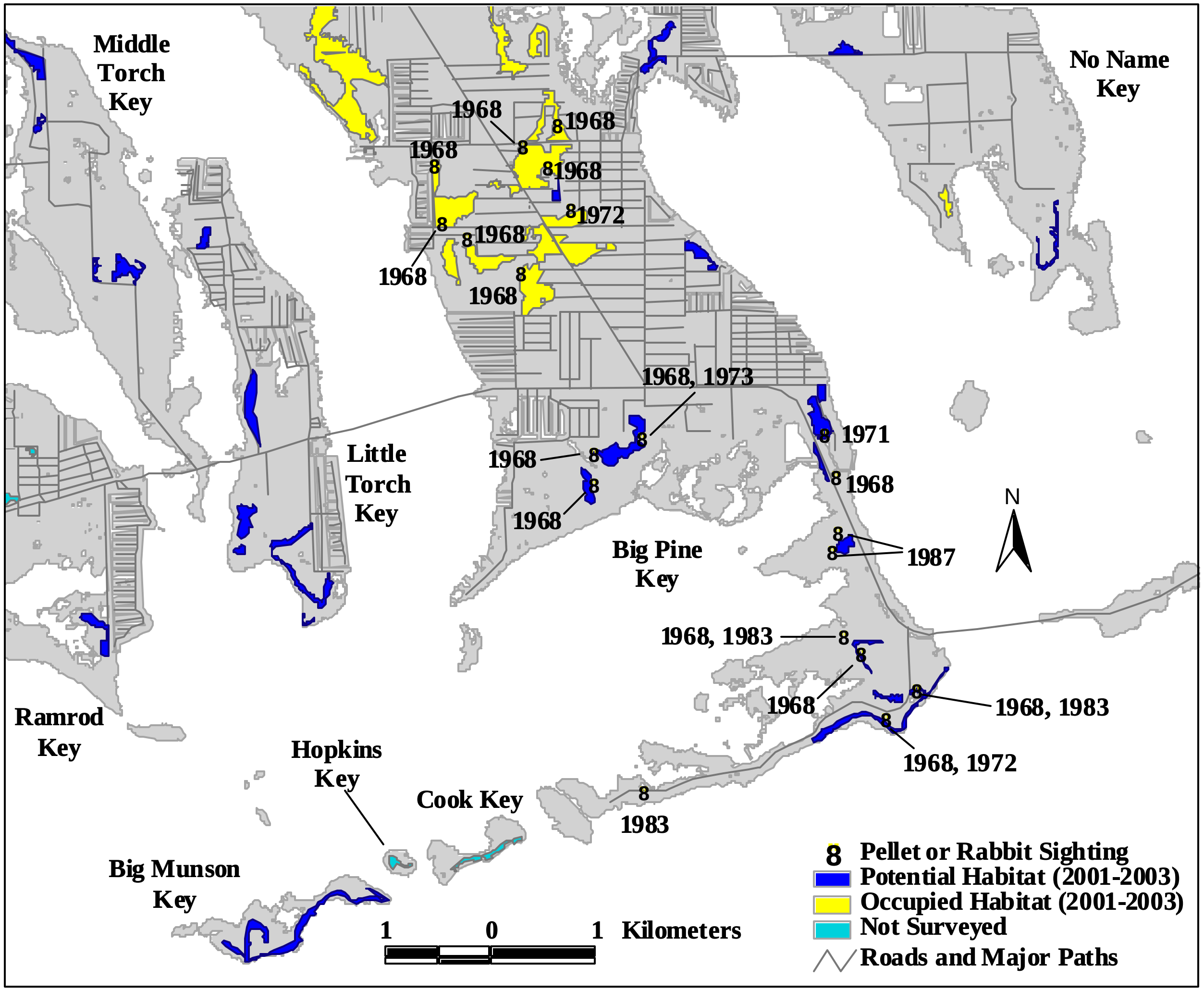

Fig. 2.15. Observations of Lower Keys marsh rabbits or their fecal pellets recorded on blue-line aerial photographs for the period 1968–1987. Occupied and potential habitat patches from the 2001–2003 fecal pellet survey are shown for comparison.

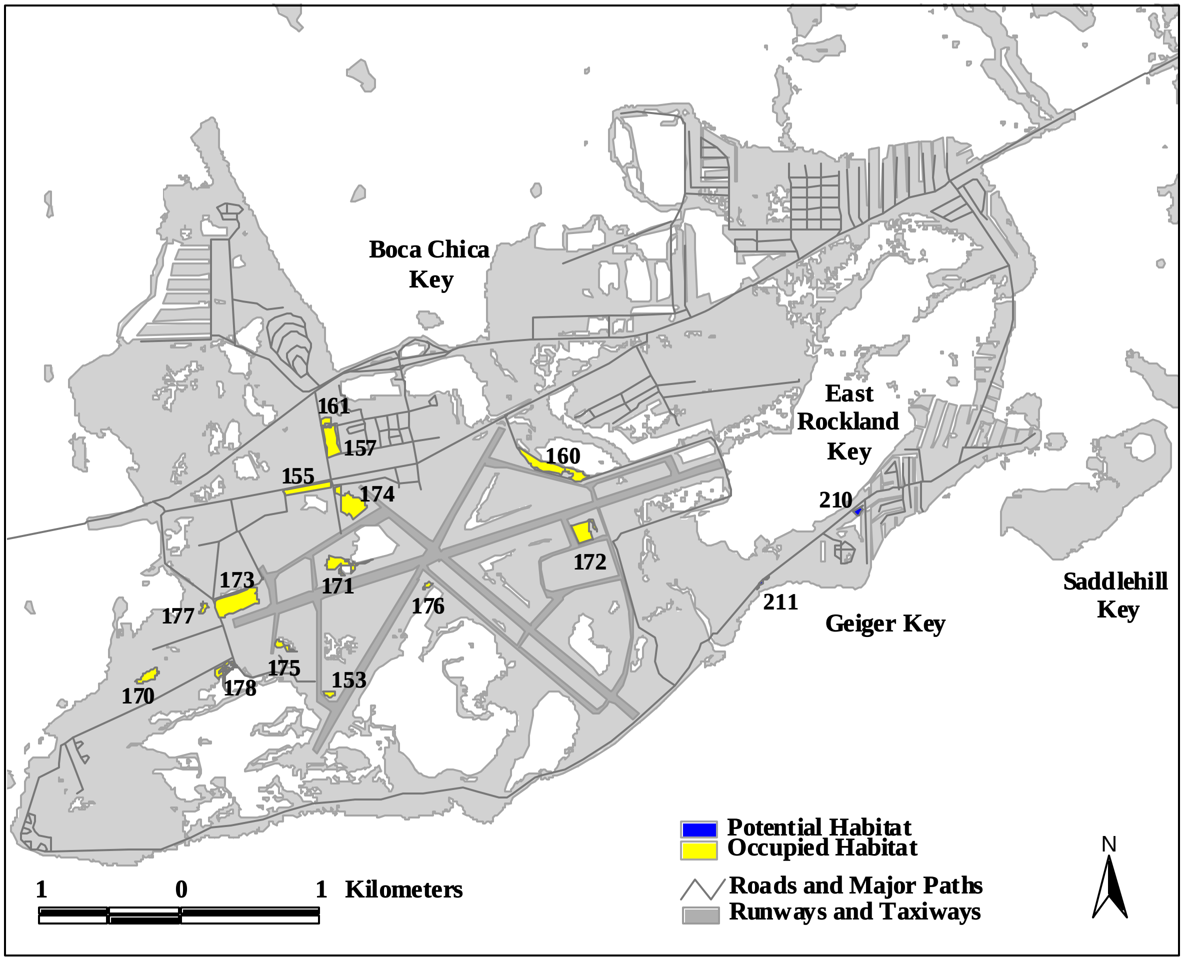

Fig. 2.16. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on Boca Chica Key in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

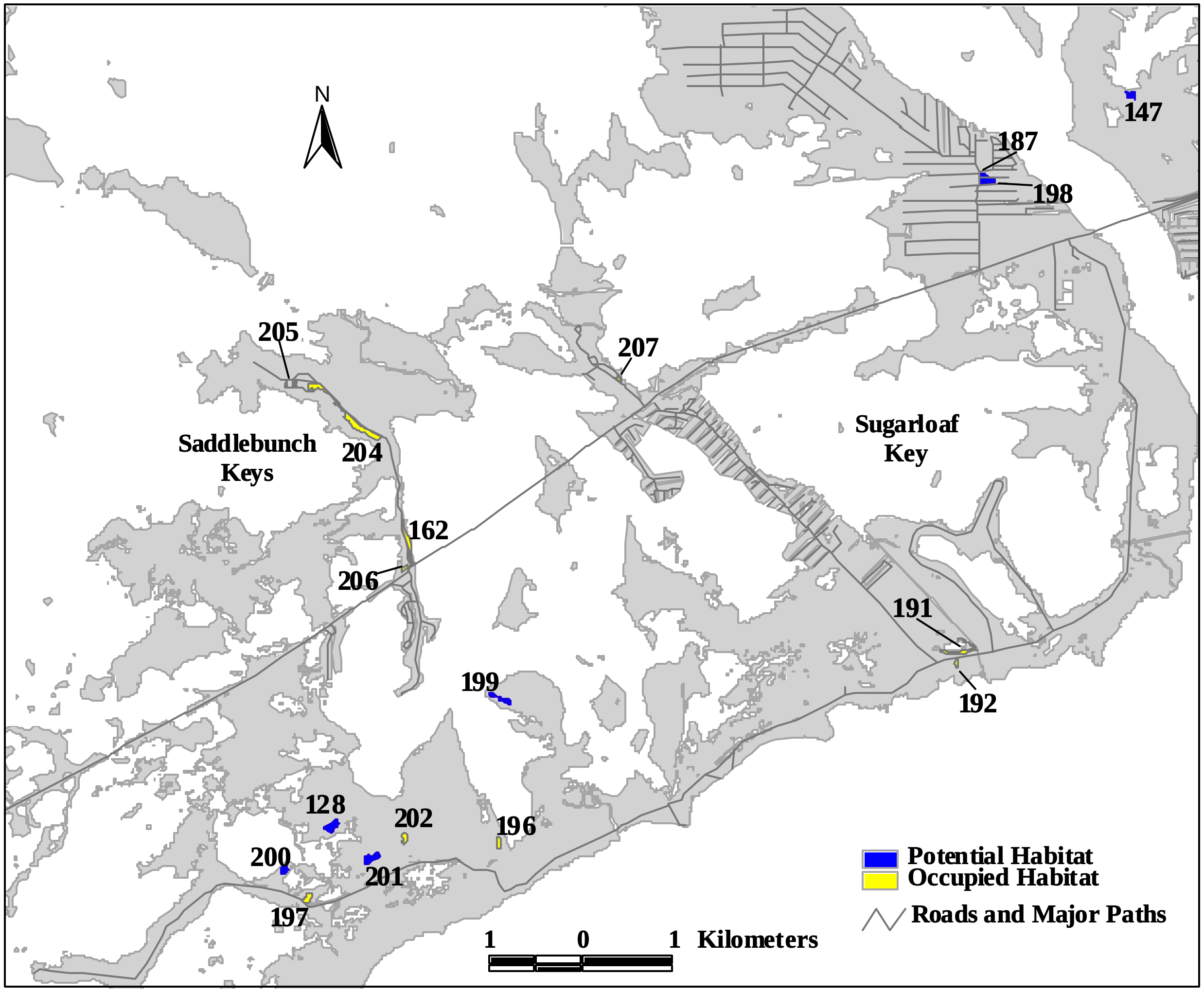

Fig. 2.17. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on Sugarloaf and the Saddlebunch keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

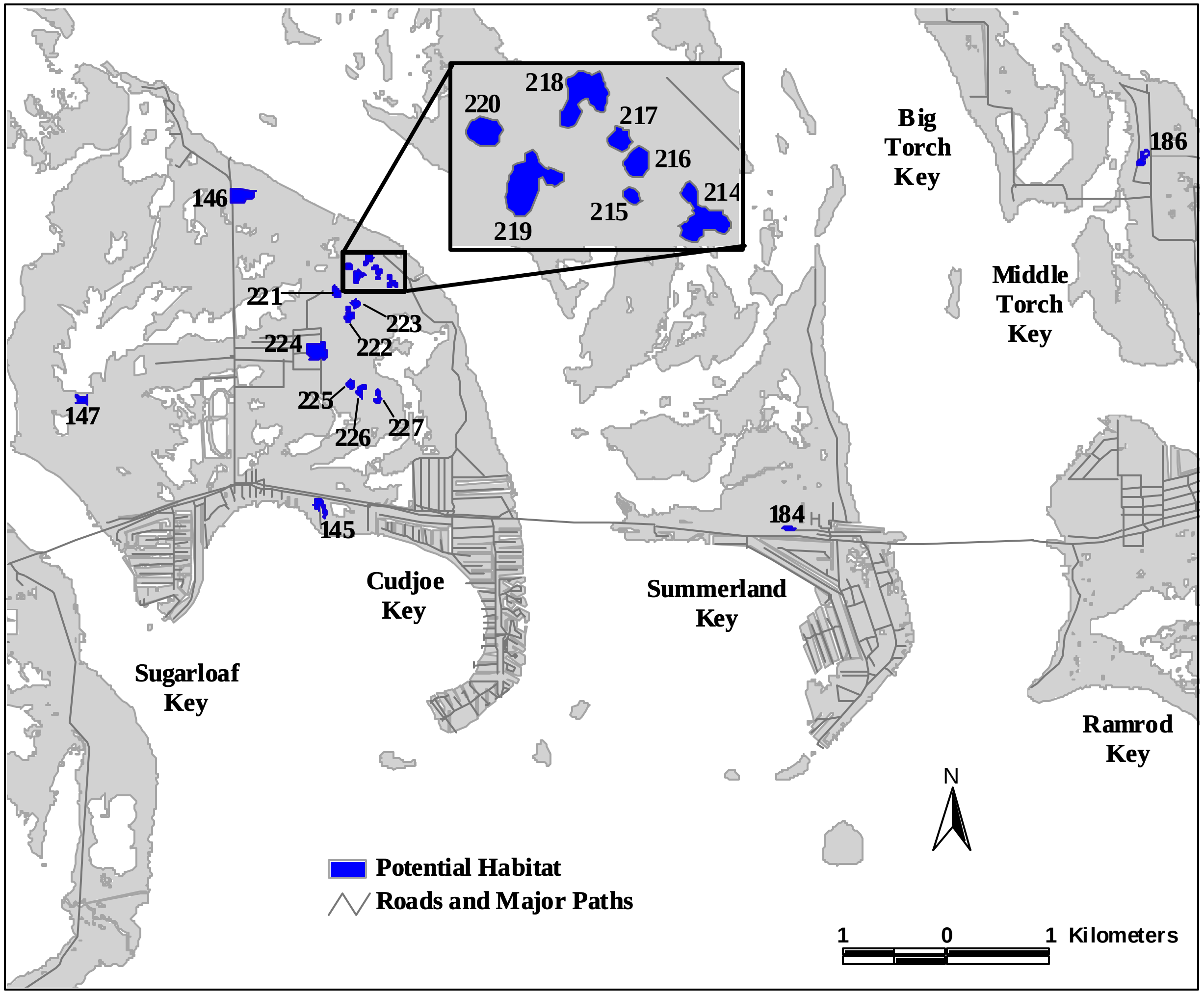

Fig. 2.18. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on Cudjoe and Summerland keys and a portion of Middle Torch Key in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

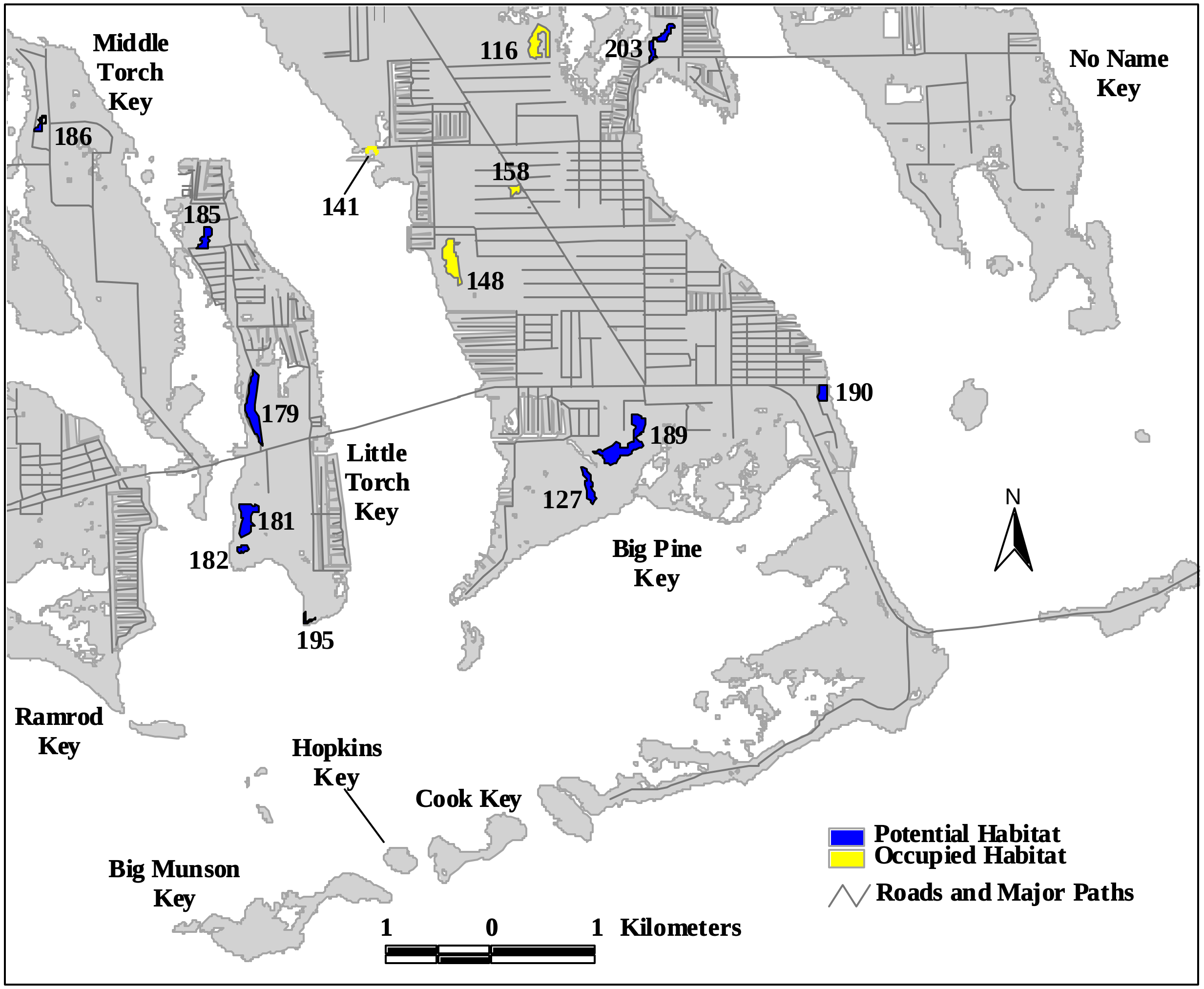

Fig. 2.19. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on Middle Torch and Little Torch keys and portions of Ramrod and Big Pine keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in $\geq$1 survey during this period.

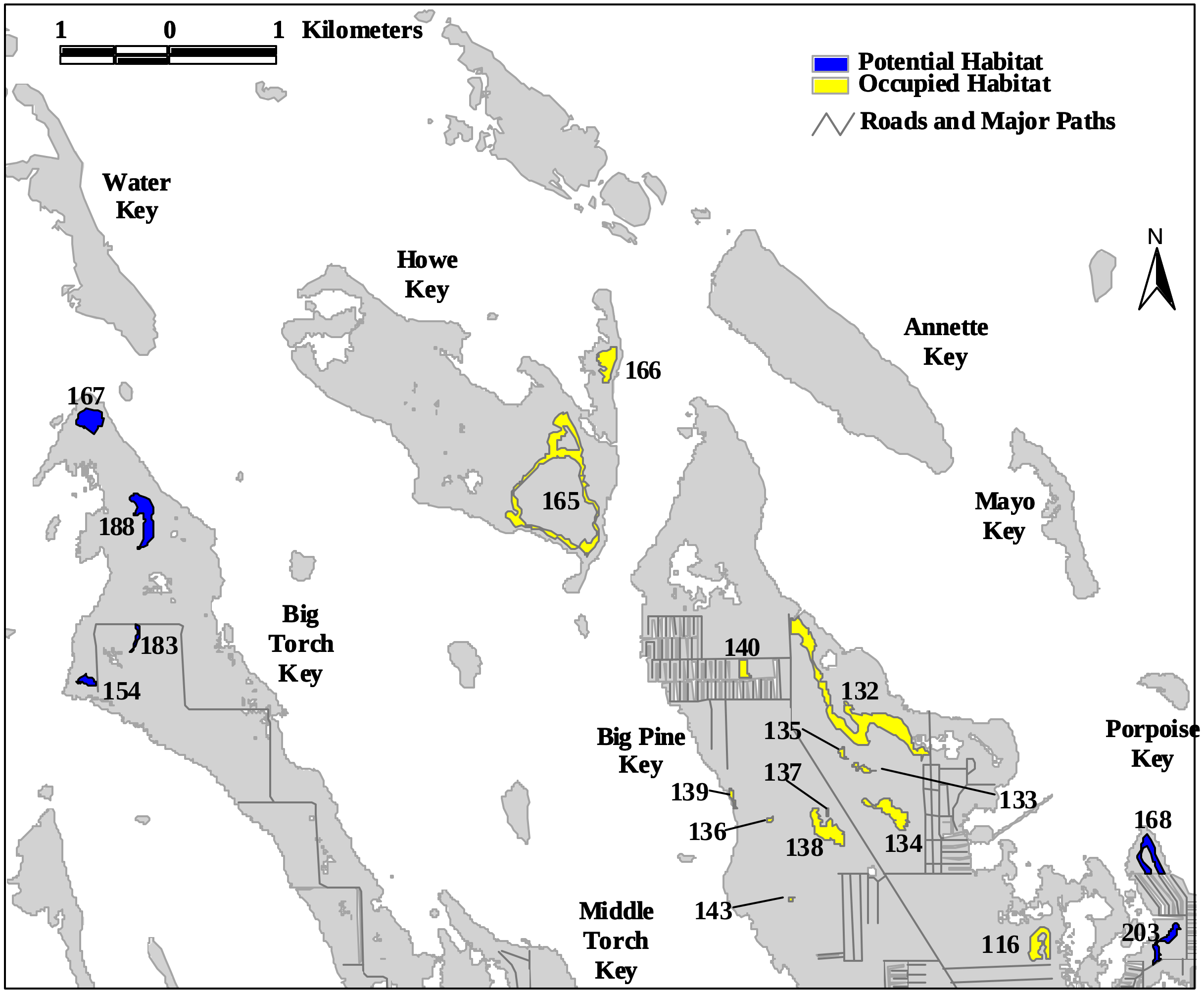

Fig. 2.20. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on Big Torch and Water keys and portions of Big Pine Key in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in $\geq$1 survey during this period.

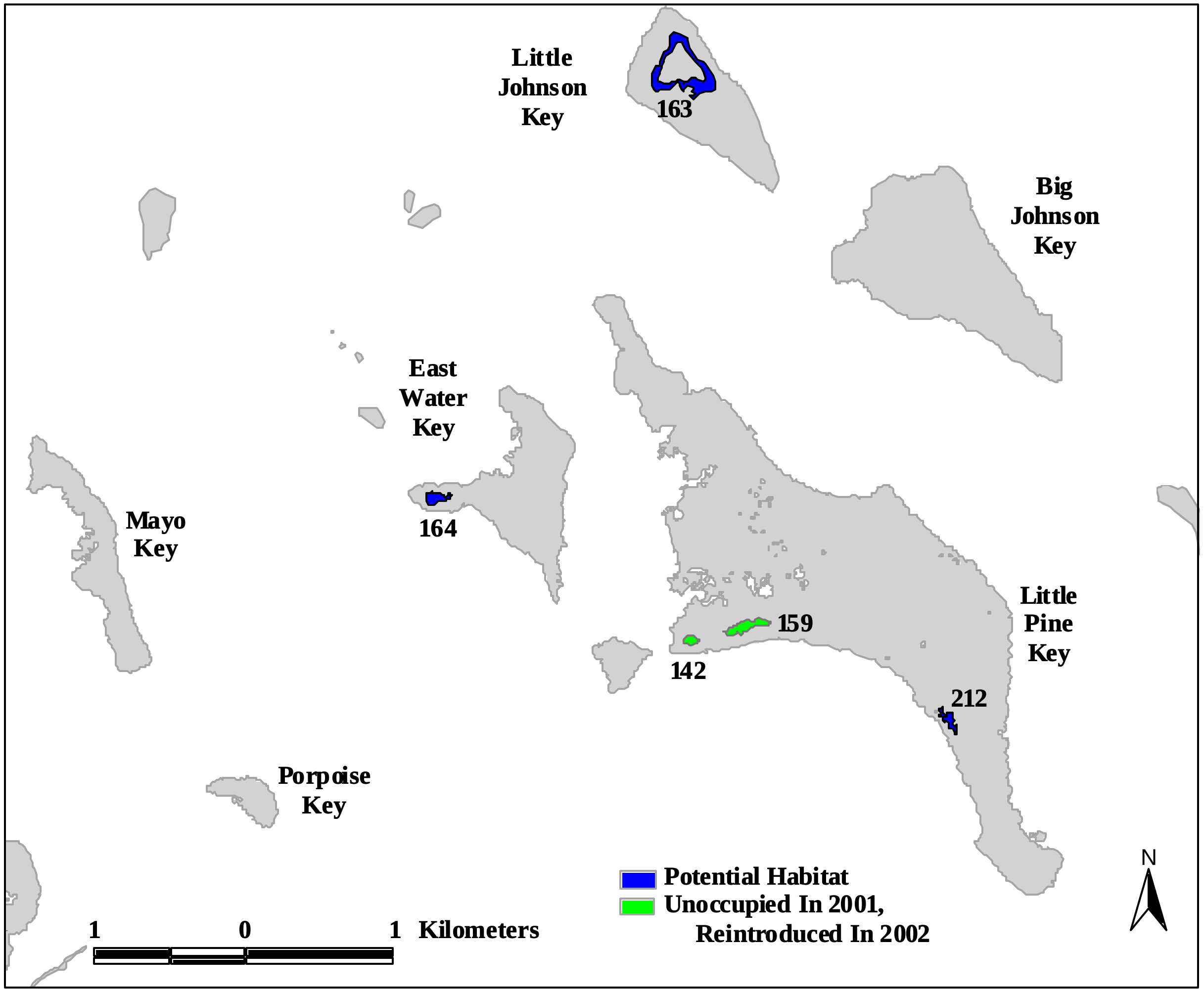

Fig. 2.21. Newly-documented patches of occupied and potential Lower Keys marsh rabbit habitat on East Water, Little Pine, and the Johnson keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

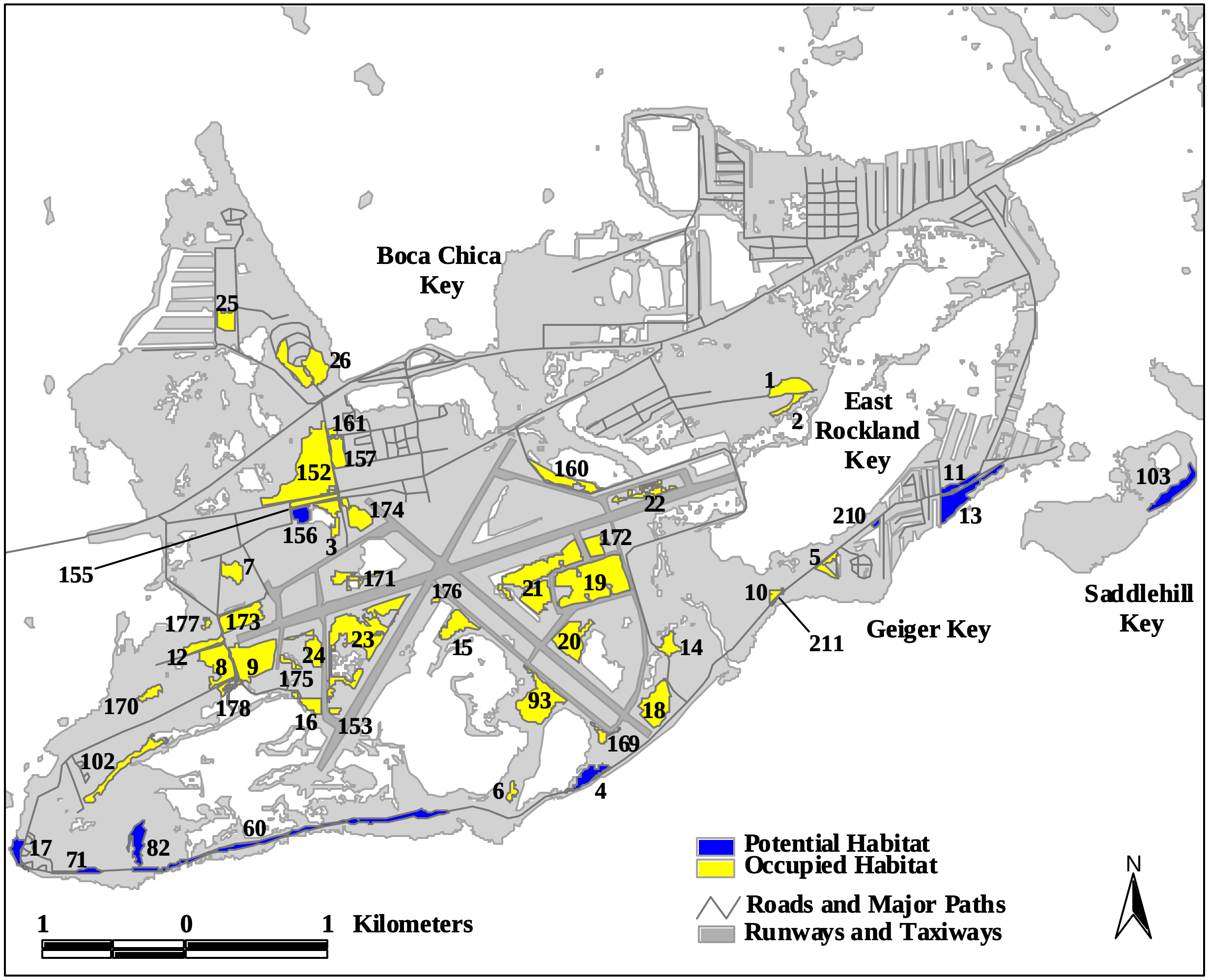

Fig. 2.22. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Boca Chica, East Rockland, Geiger, and Saddlehill keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

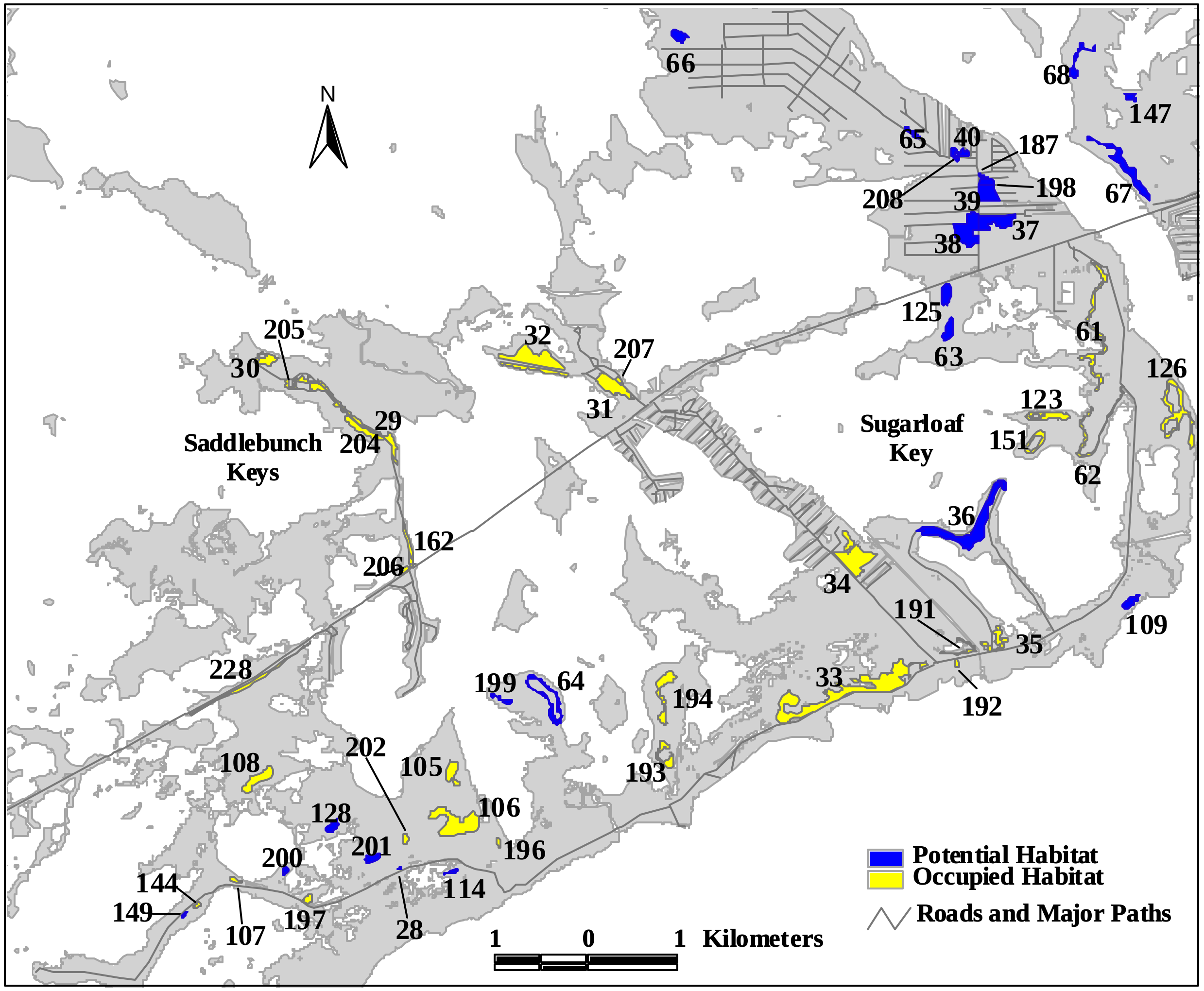

Fig. 2.23. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Sugarloaf and the Saddlebunch keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

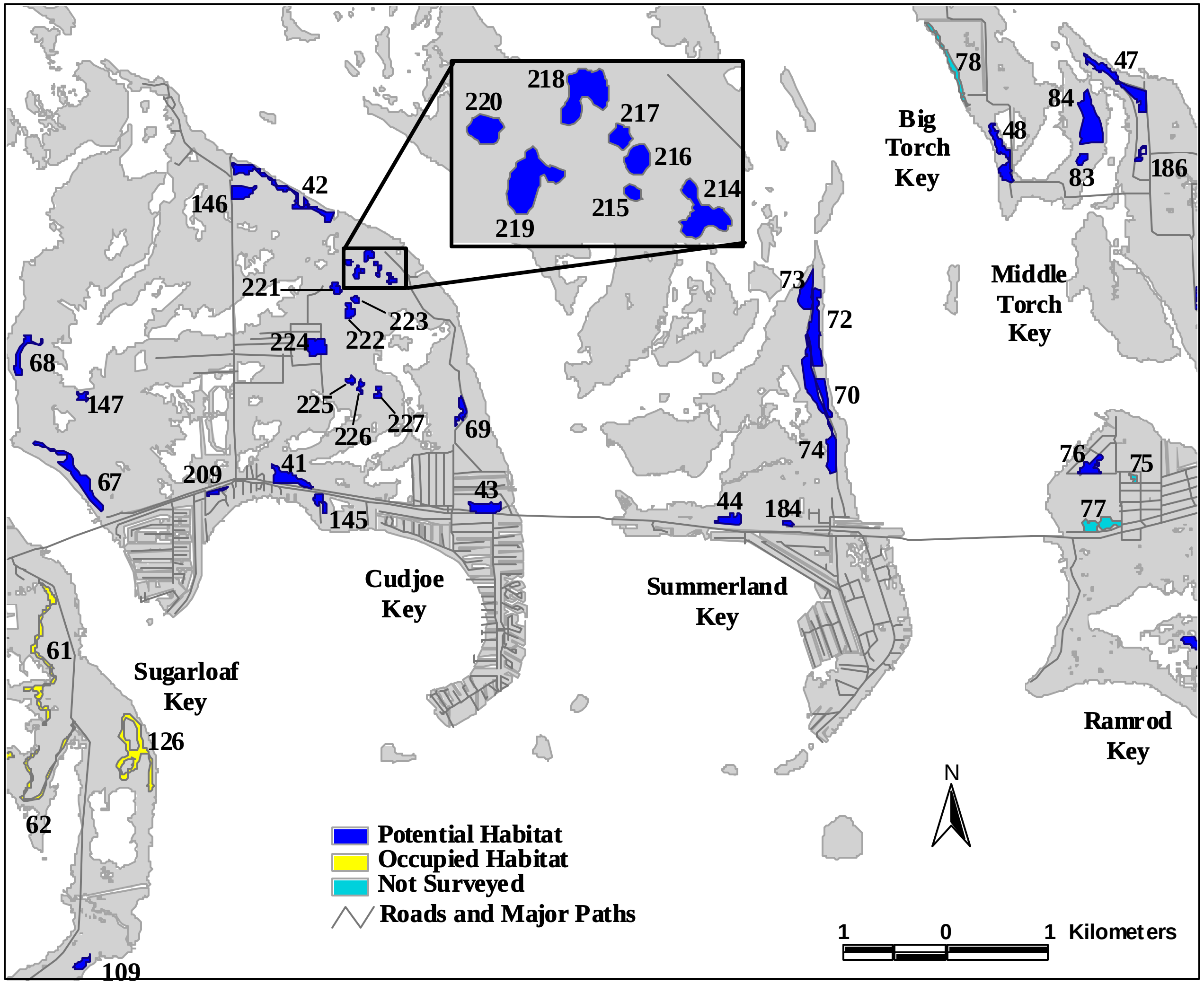

Fig. 2.24. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

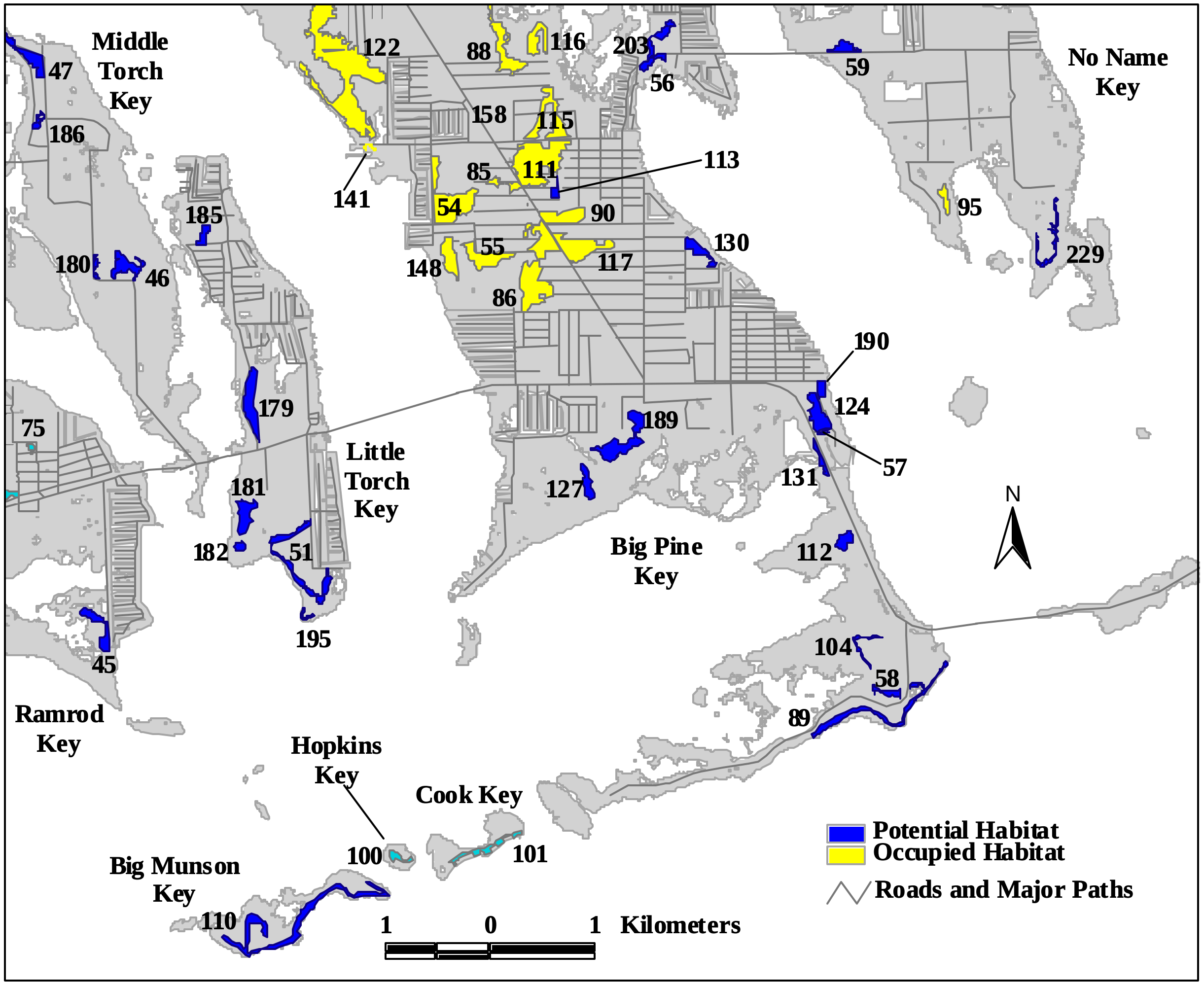

Fig. 2.25. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Middle Torch, Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Ramrod and Big Pine keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥ 1 survey during this period.

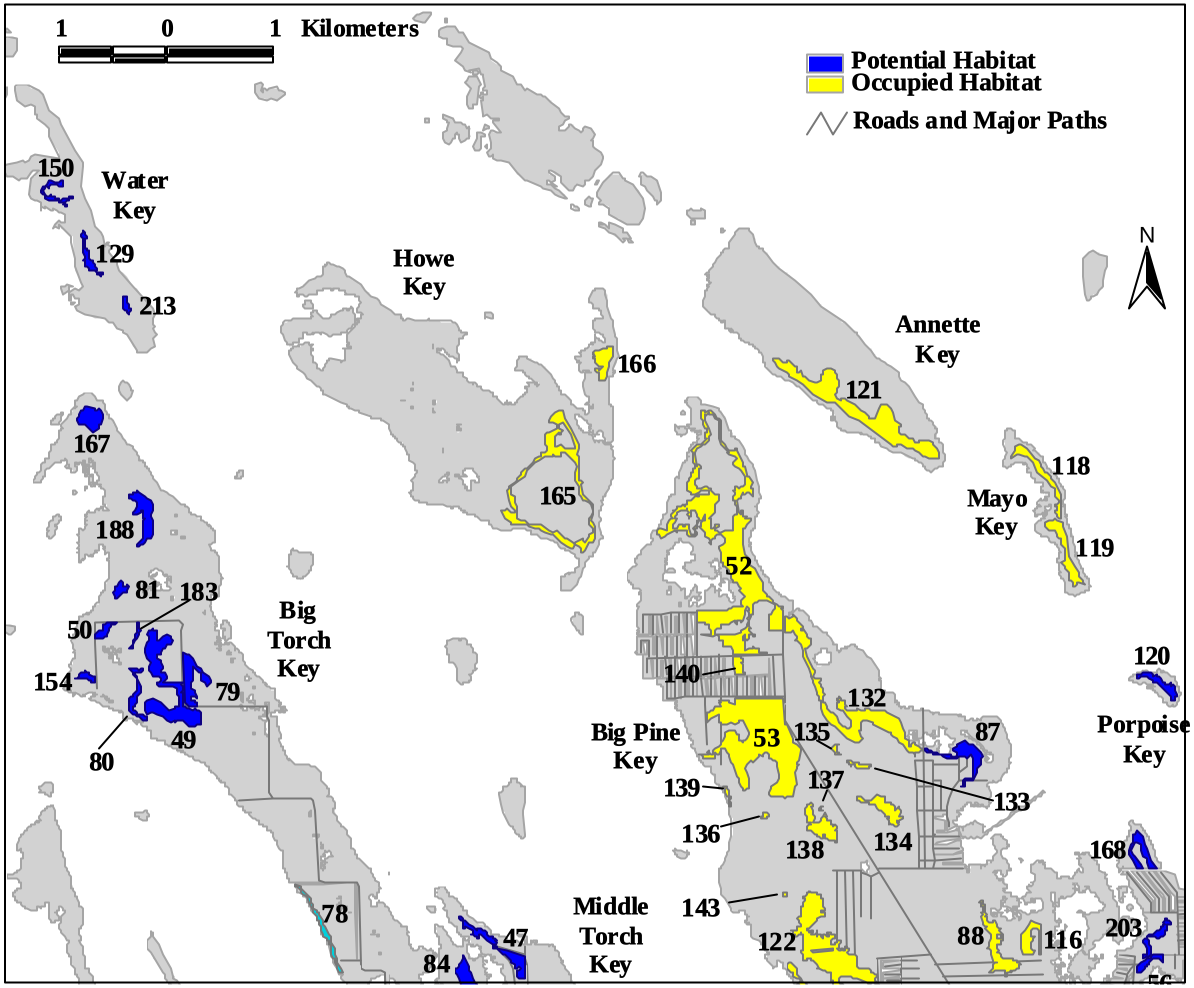

Fig. 2.26. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Big Torch, Water, Howe, Annette, Mayo, and Porpoise keys and portions of Middle Torch and Big Pine keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

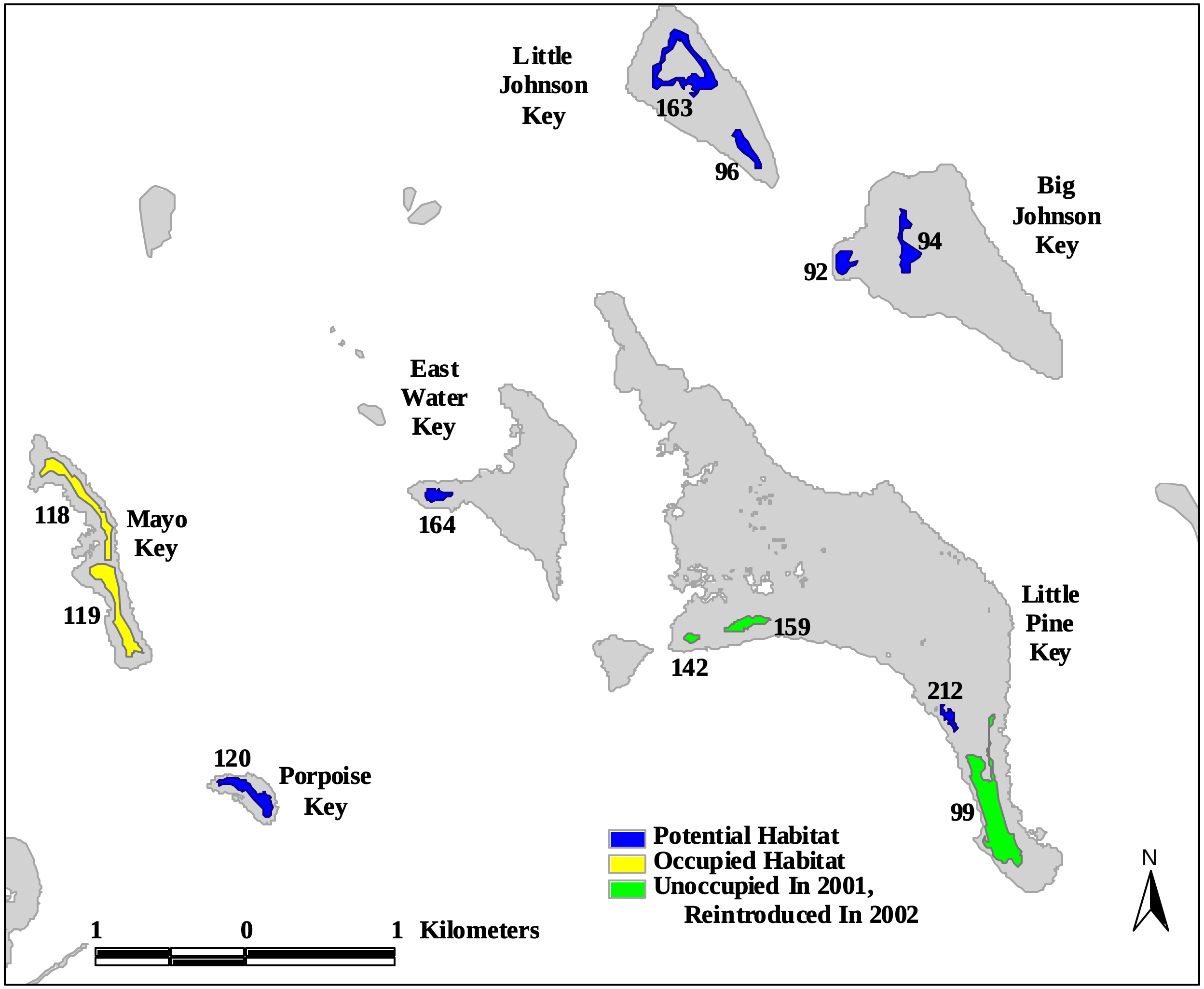

Fig. 2.27. Distribution of occupied and potential Lower Keys marsh rabbit habitat on Mayo, Porpoise, East Water, Little Pine, and the Johnson keys in surveys conducted 2001–2003. A habitat patch was considered to be occupied if fecal pellets were discovered in ≥1 survey during this period.

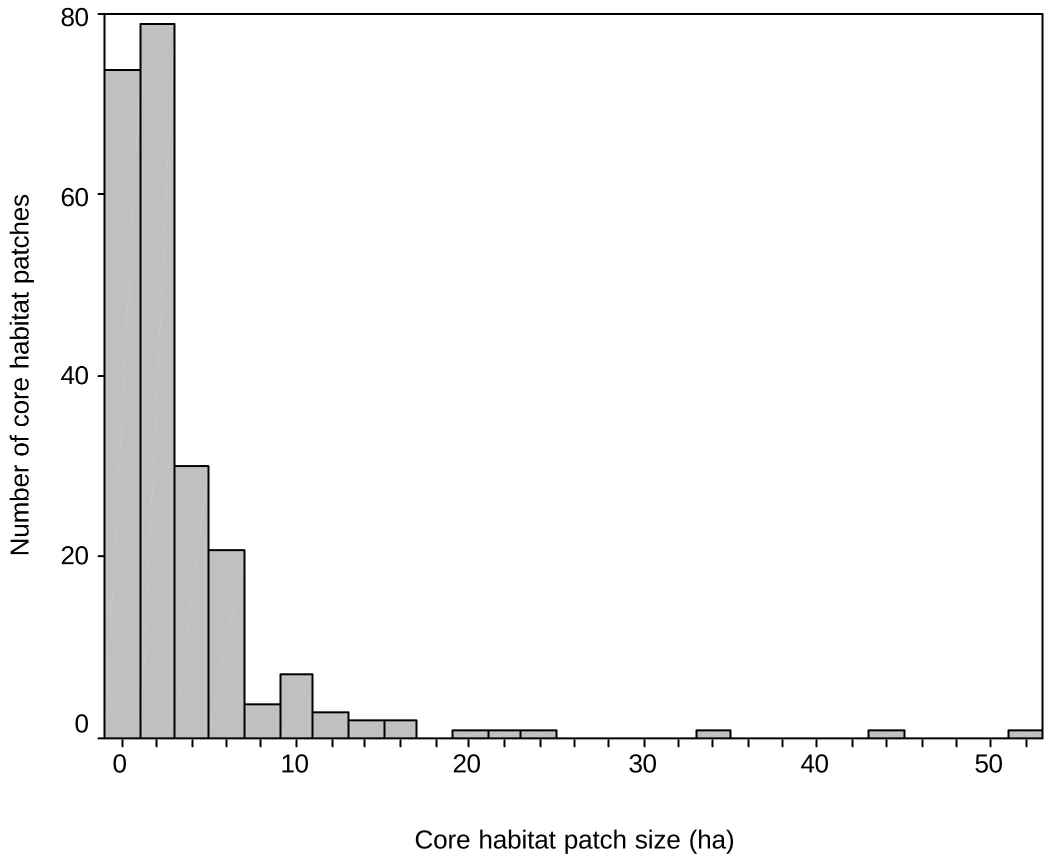

Fig. 2.28. Size (ha) of all occupied and potential habitat patches of the Lower Keys marsh rabbit in the Lower Keys of Florida, USA, in 2001–2003.

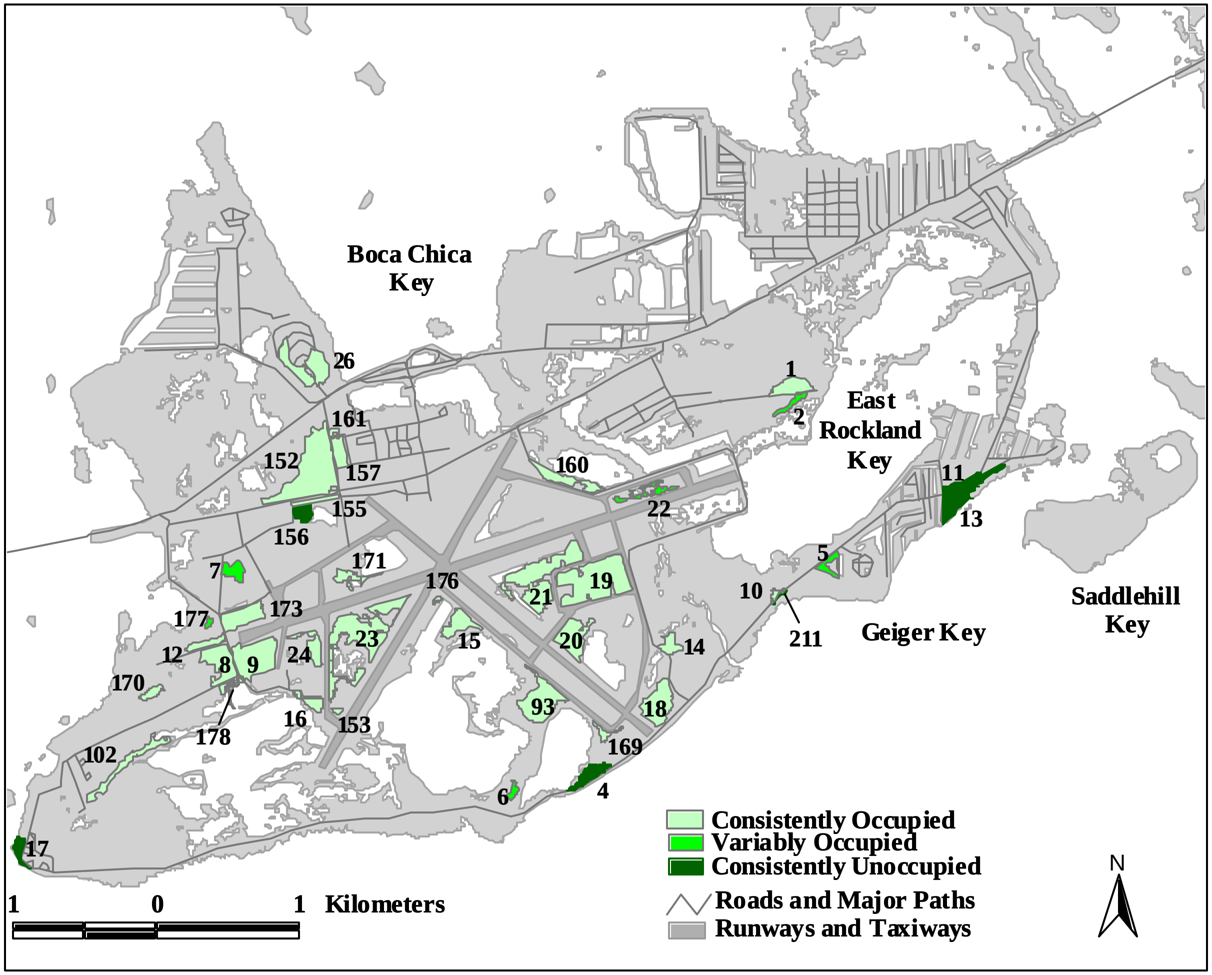

Fig. 2.29. Variability in occupancy for Lower Keys marsh rabbit habitat patches on Boca Chica, East Rockland, Geiger, and Saddlehill keys that were visited >1 time during surveys conducted 2001–2003. Patches with fecal pellets in all surveys were considered to be "consistently occupied." Patches with fecal pellets in $\geq$1 but not all surveys were considered to be "variably occupied."

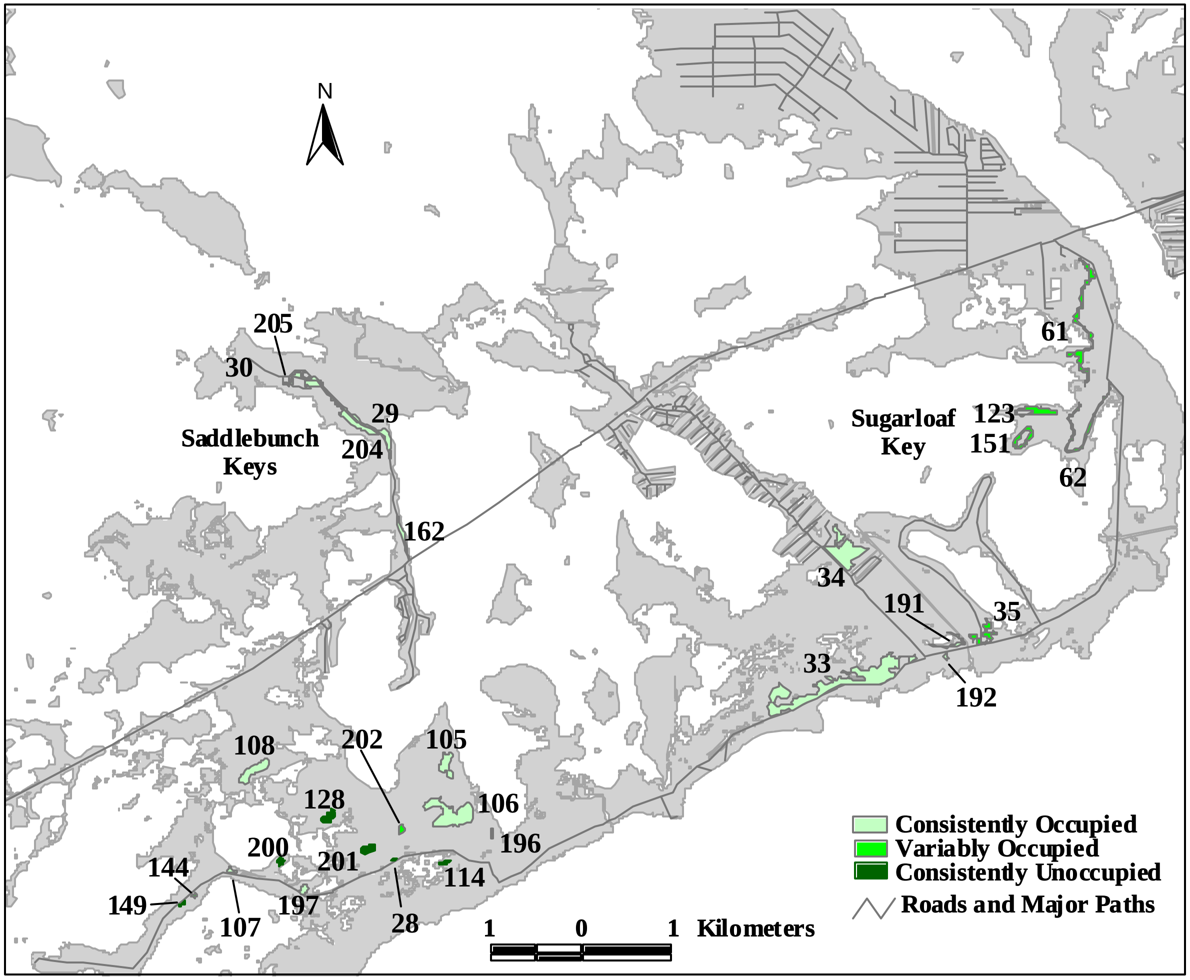

Fig. 2.30. Variability in occupancy for Lower Keys marsh rabbit habitat patches on Sugarloaf and the Saddlebunch keys that were visited >1 time during surveys conducted 2001–2003. Patches with fecal pellets in all surveys were considered to be “consistently occupied.” Patches with fecal pellets in $\geq$1 but not all surveys were considered to be “variably occupied.”

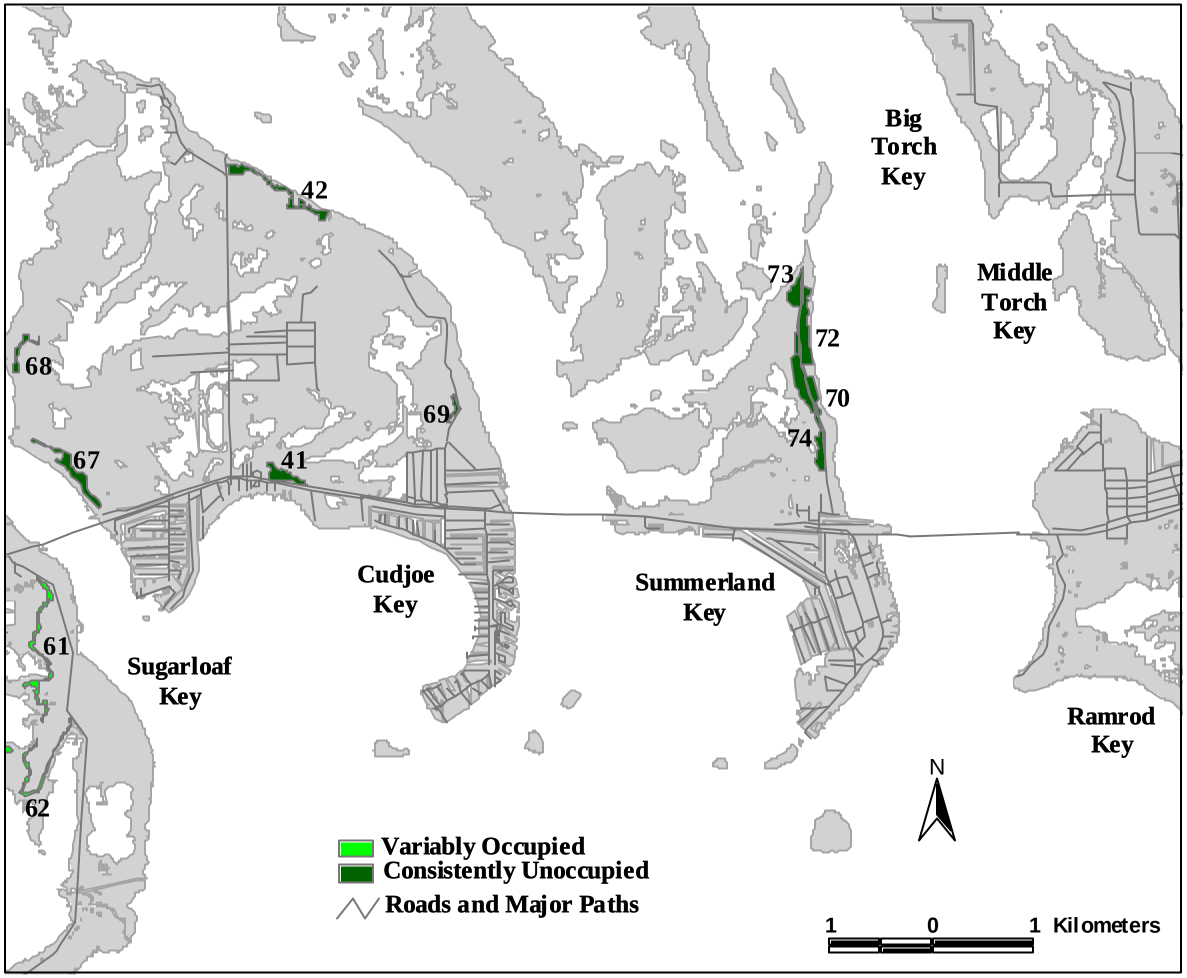

Fig. 2.31. Variability in occupancy for Lower Keys marsh rabbit habitat patches on Cudjoe and Summerland keys and portions of Sugarloaf Key that were visited >1 time during surveys conducted 2001–2003. Patches with fecal pellets in all surveys were considered to be "consistently occupied." Patches with fecal pellets in ≥1 but not all surveys were considered to be "variably occupied."

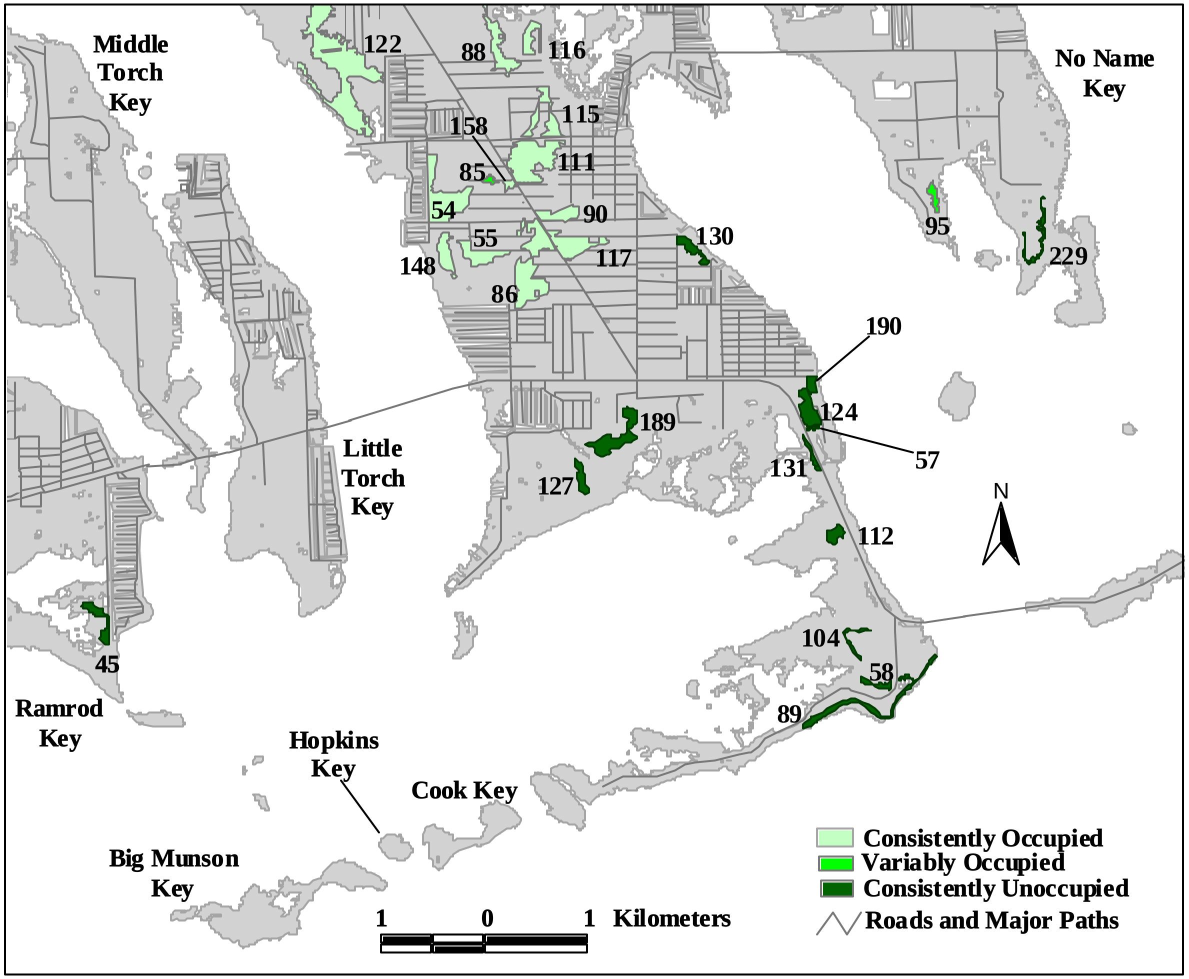

Fig. 2.32. Variability in occupancy for Lower Keys marsh rabbit habitat patches on No Name Key and portions of Ramrod and Big Pine keys that were visited >1 time during surveys conducted 2001–2003. Patches with fecal pellets in all surveys were considered to be "consistently occupied." Patches with fecal pellets in $\geq$1 but not all surveys were considered to be "variably occupied."

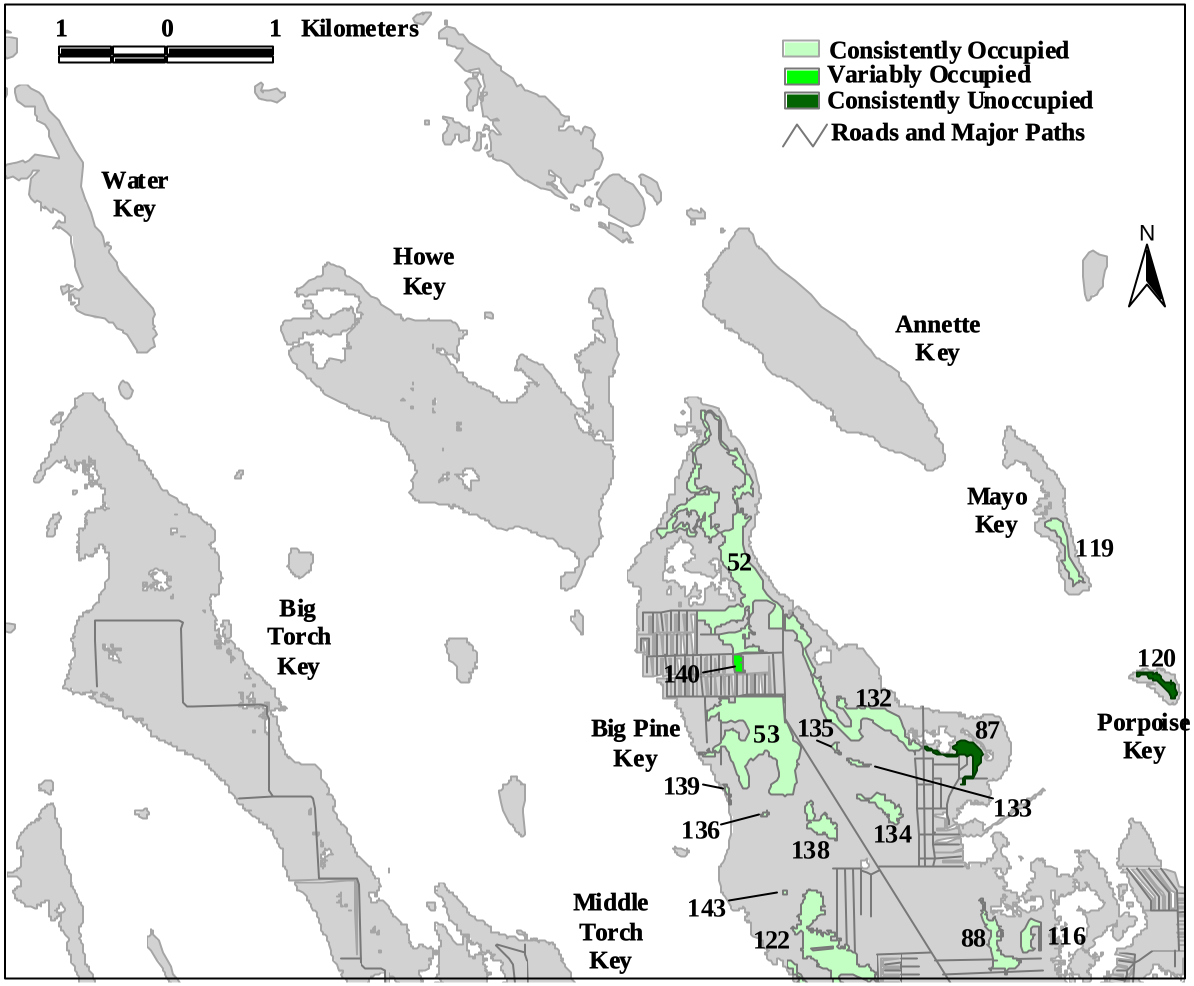

Fig. 2.33. Variability in occupancy for Lower Keys marsh rabbit habitat patches on Mayo and Porpoise keys and portions of Middle Torch and Big Pine keys that were visited >1 time during surveys conducted 2001–2003. Patches with fecal pellets in all surveys were considered to be “consistently occupied.” Patches with fecal pellets in $\geq$1 but not all surveys were considered to be “variably occupied.”

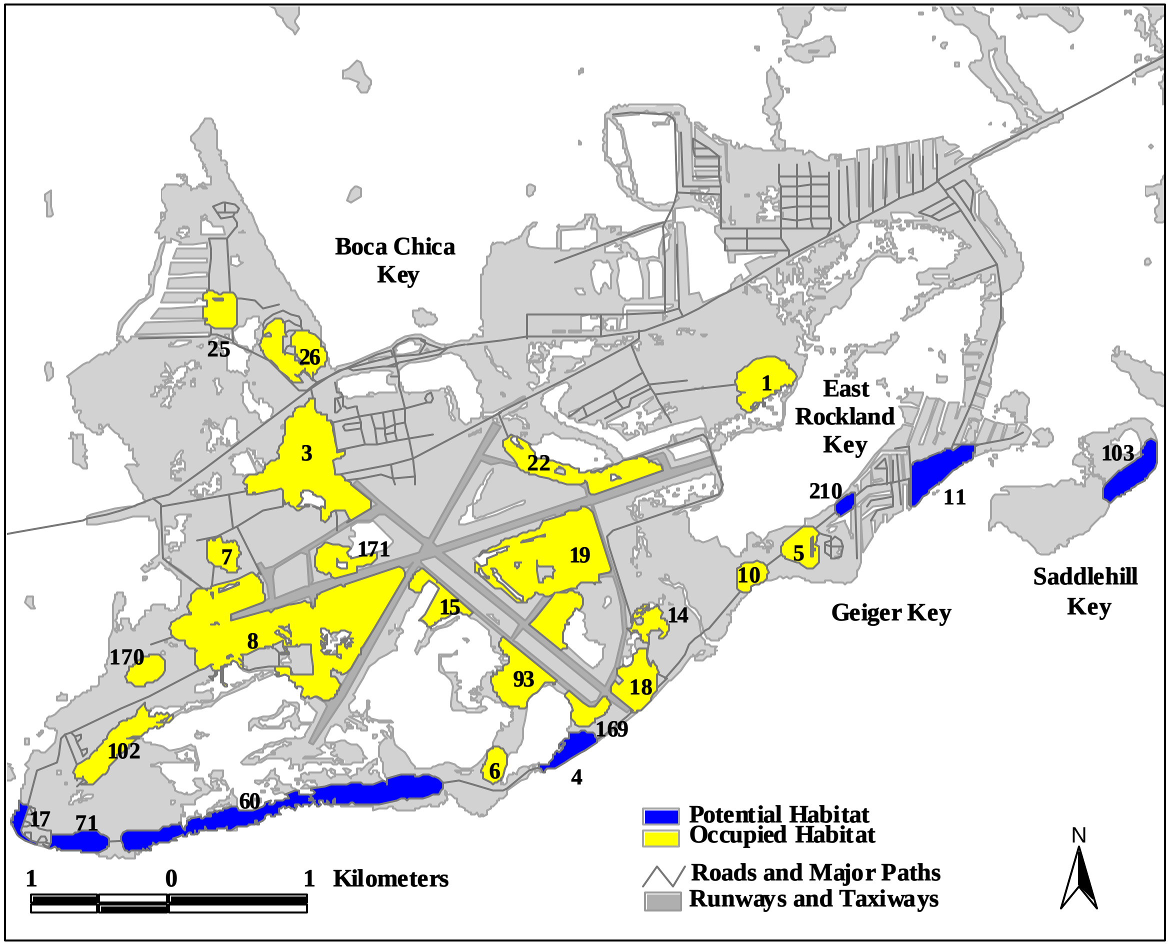

Fig. 2.34. Occupied and potential Lower Keys marsh rabbit populations on Boca Chica, East Rockland, Geiger, and Saddlehill keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

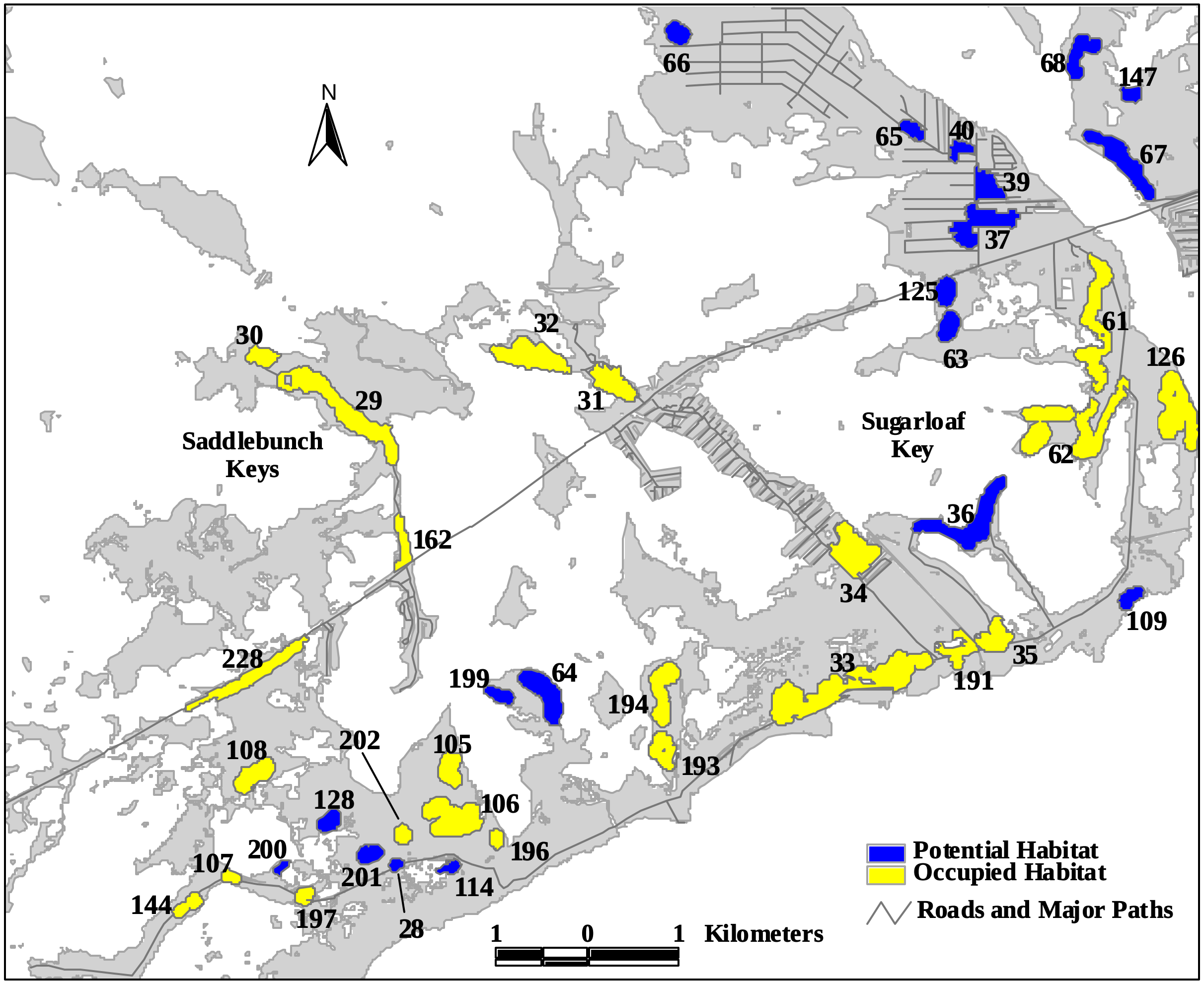

Fig. 2.35. Occupied and potential Lower Keys marsh rabbit populations on Sugarloaf and the Saddlebunch keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

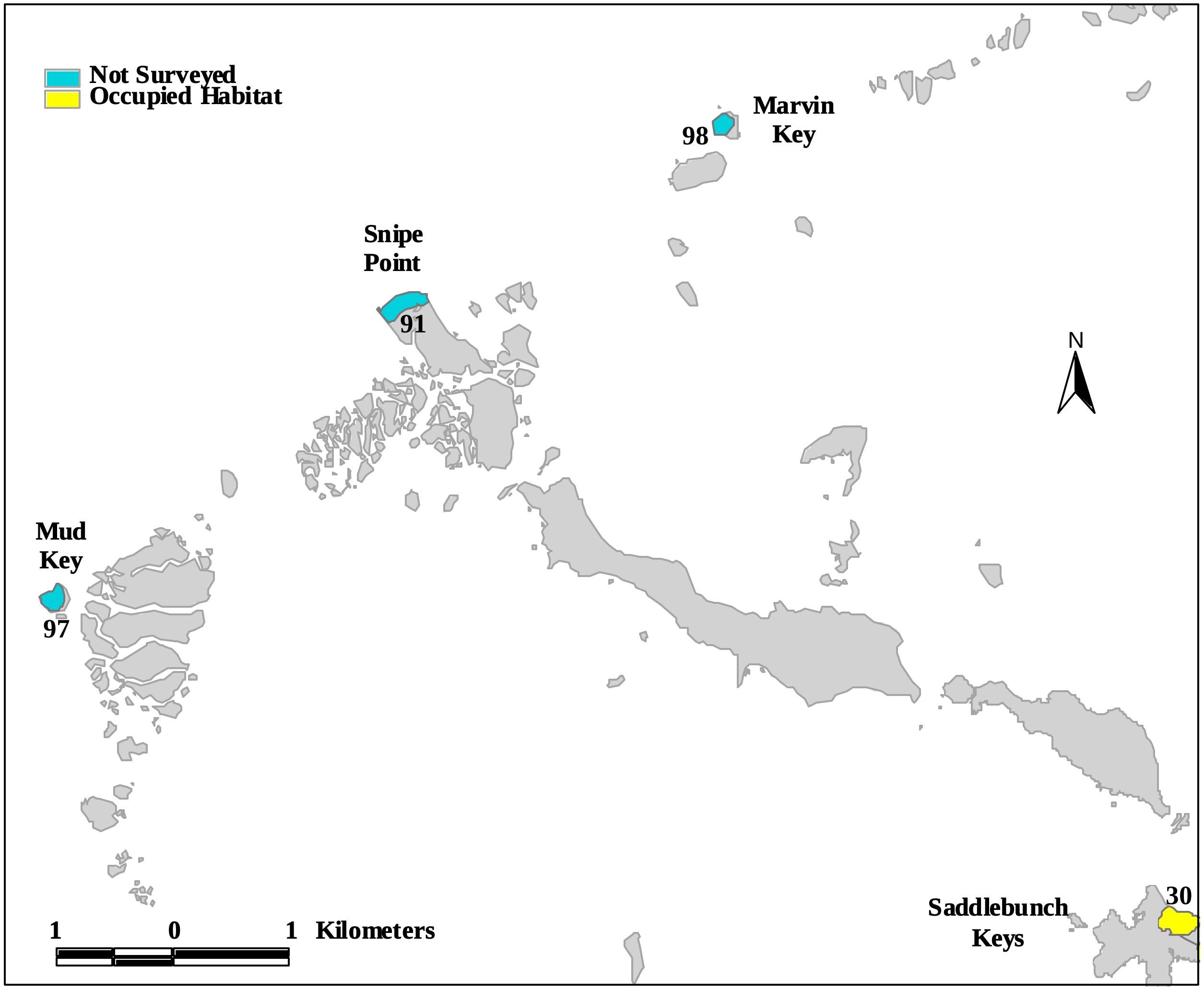

Fig. 2.36. Occupied and potential Lower Keys marsh rabbit populations on Mud, Snipe Point, and Marvin keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

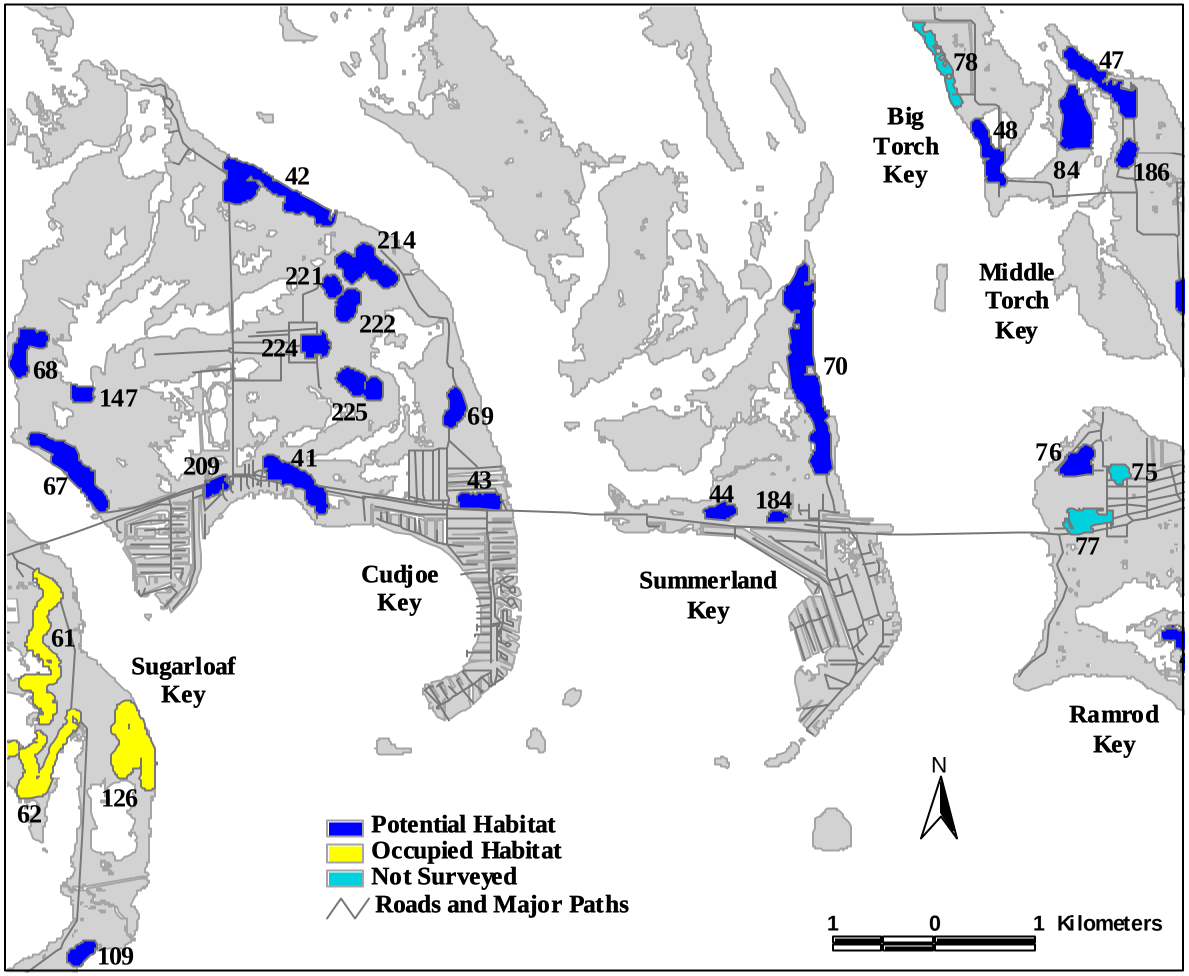

Fig. 2.37. Occupied and potential Lower Keys marsh rabbit populations on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in $\geq$1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

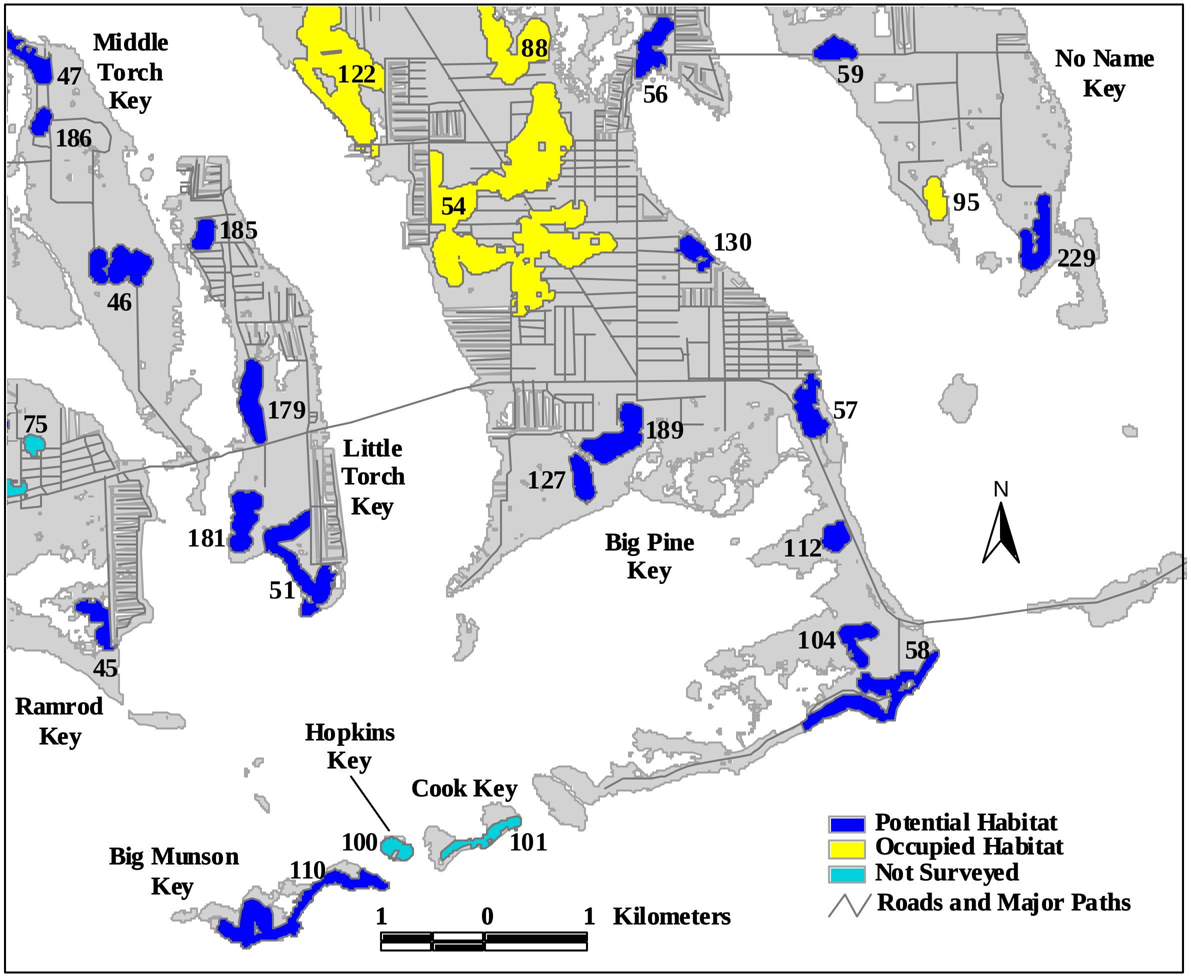

Fig. 2.38. Occupied and potential Lower Keys marsh rabbit populations on Middle Torch, Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Ramrod and Big Pine keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

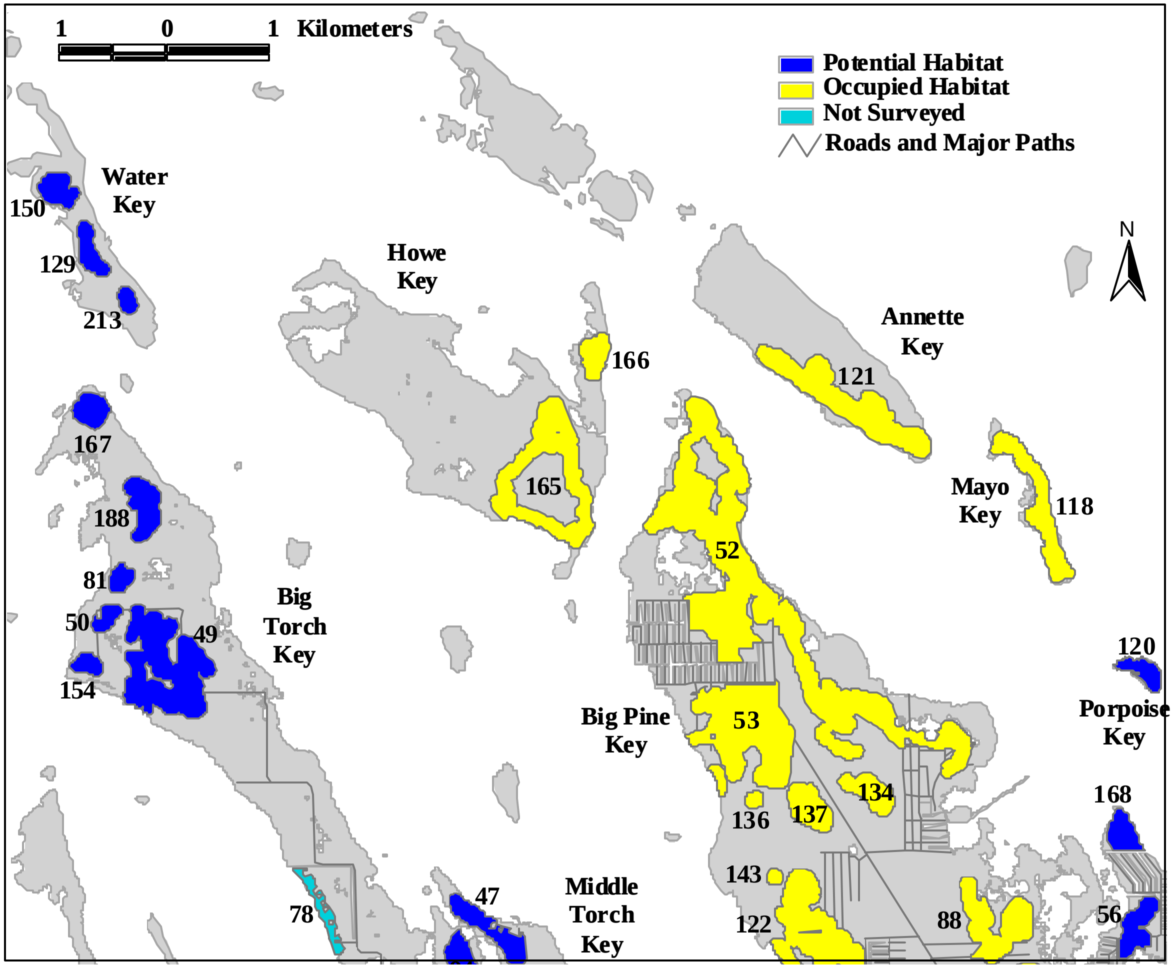

Fig. 2.39. Occupied and potential Lower Keys marsh rabbit populations on Big Torch, Water, Howe, Annette, Mayo, and Porpoise keys and portions of Middle Torch and Big Pine keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in $\geq$1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

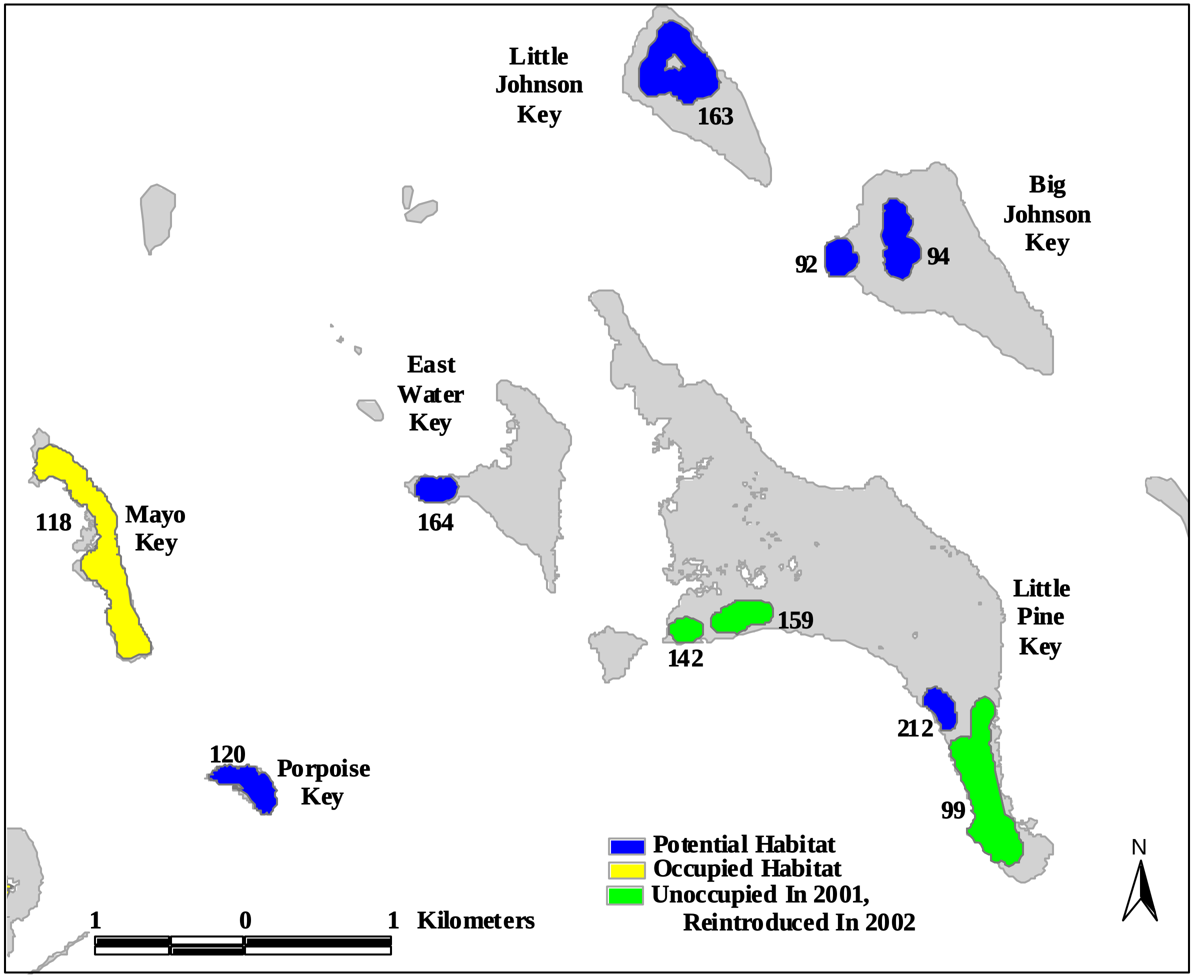

Fig. 2.40. Occupied and potential Lower Keys marsh rabbit populations on Mayo, Porpoise, East Water, Little Pine, and the Johnson keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period. Populations were given an identification number equal to the smallest identification number of the constituent patches.

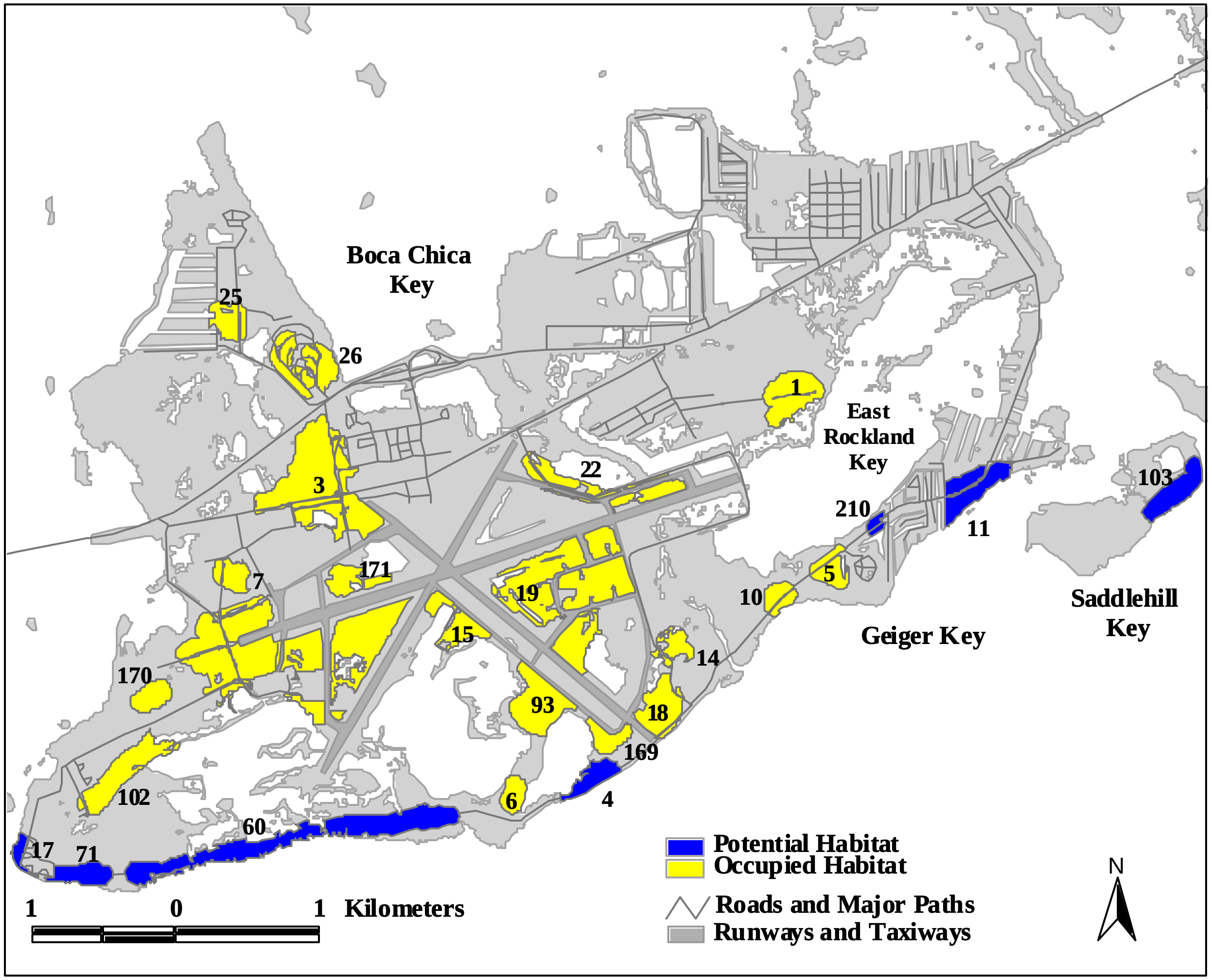

Fig. 2.41. Useable habitat (i.e., without scarified and paved areas) in occupied and potential Lower Keys marsh rabbit populations on Boca Chica, East Rockland, Geiger, and Saddlehill keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

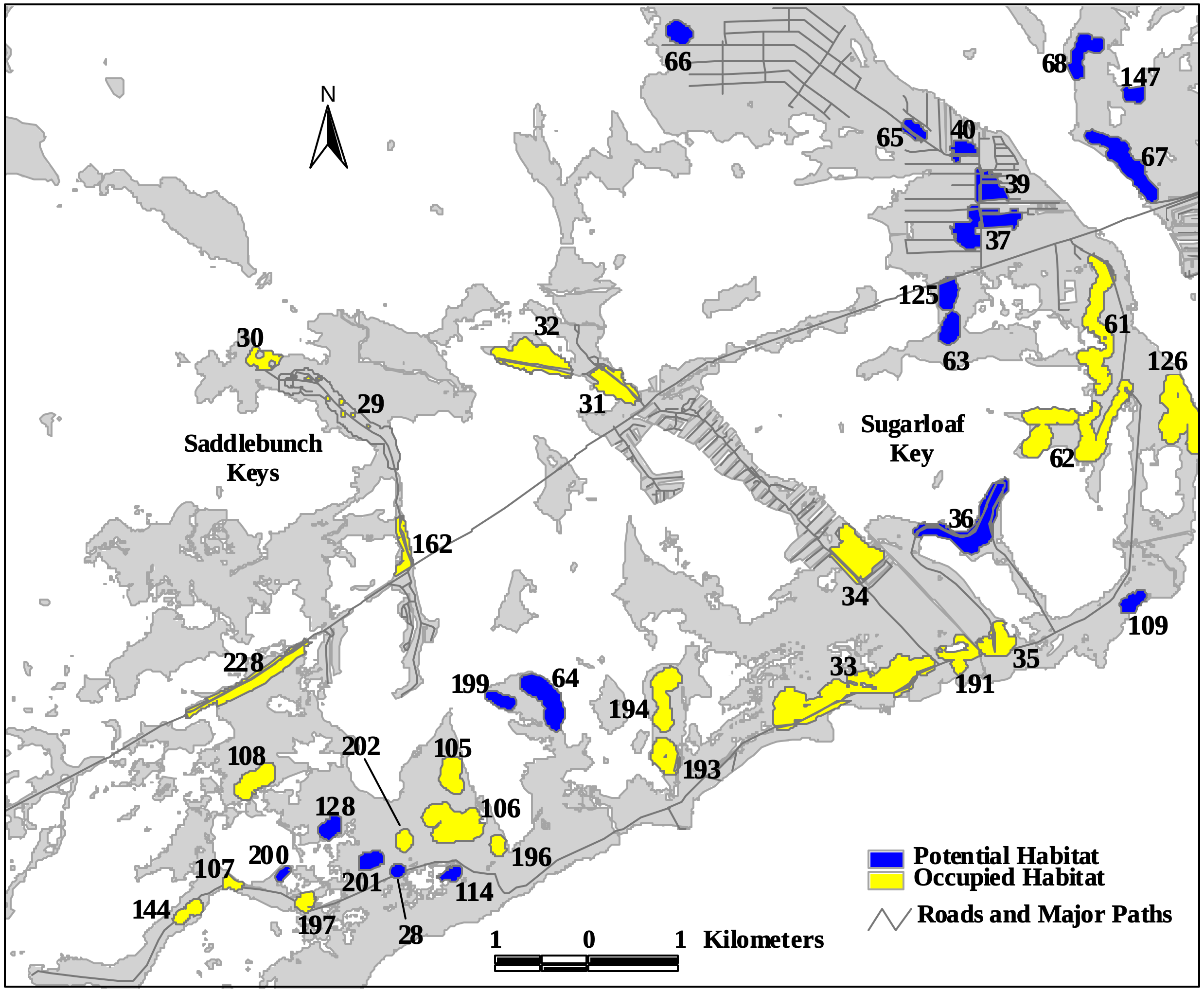

Fig 2.42. Useable habitat (i.e., without scarified and paved areas) in occupied and potential Lower Keys marsh rabbit populations on Sugarloaf and the Saddlebunch keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

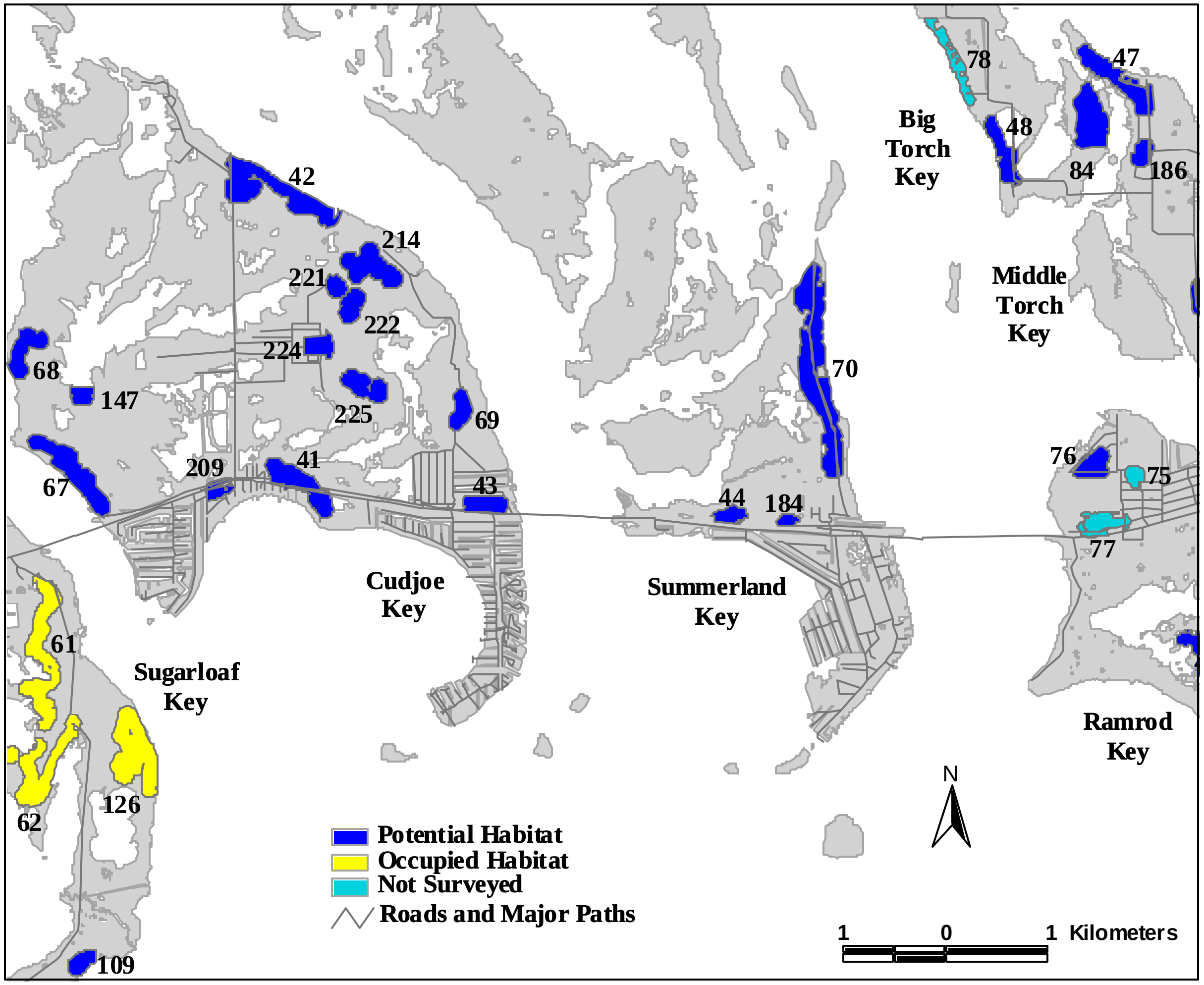

Fig. 2.43. Useable habitat (i.e., without scarified and paved areas) in occupied and potential Lower Keys marsh rabbit populations on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

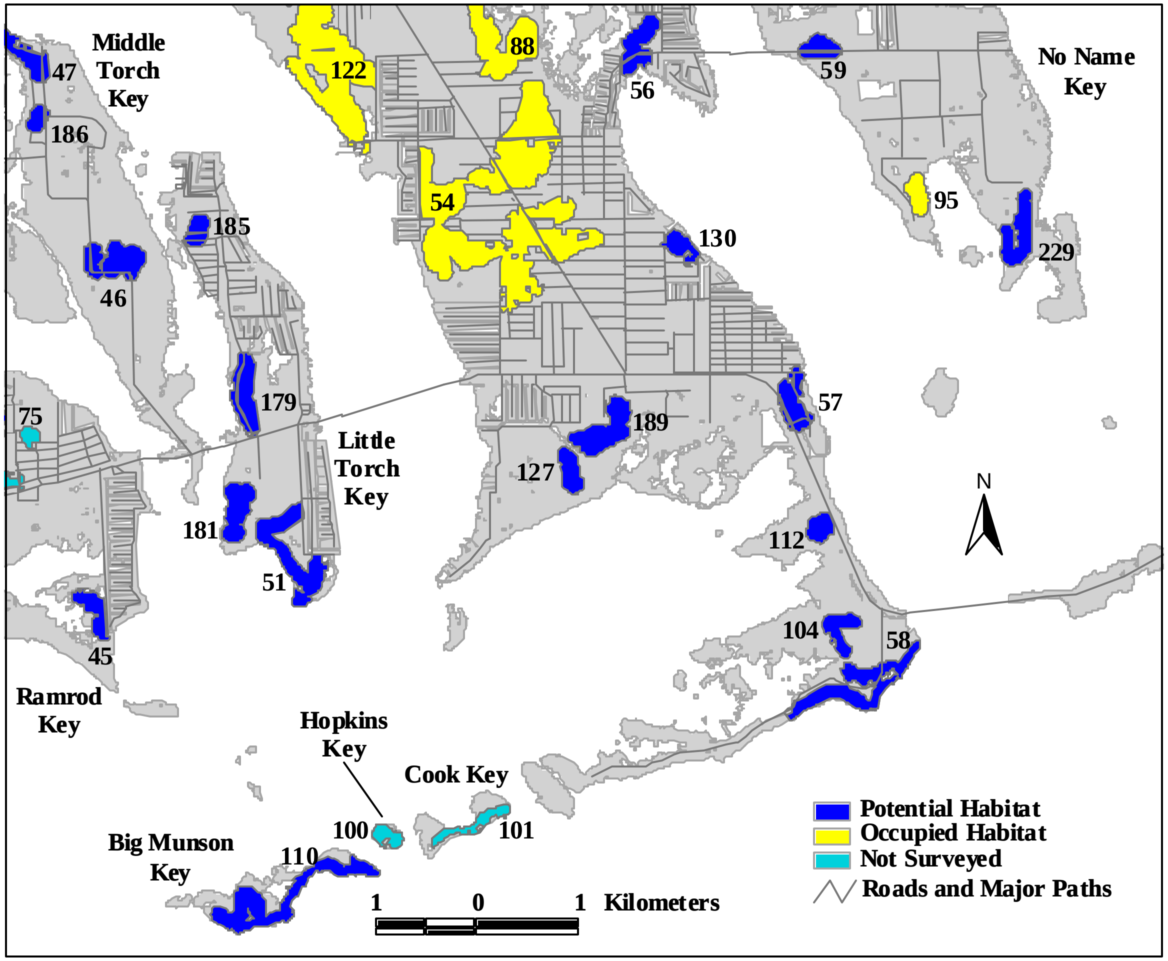

Fig. 2.44. Useable habitat (i.e., without scarified and paved areas) in occupied and potential Lower Keys marsh rabbit populations on Middle Torch, Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Ramrod and Big Pine keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

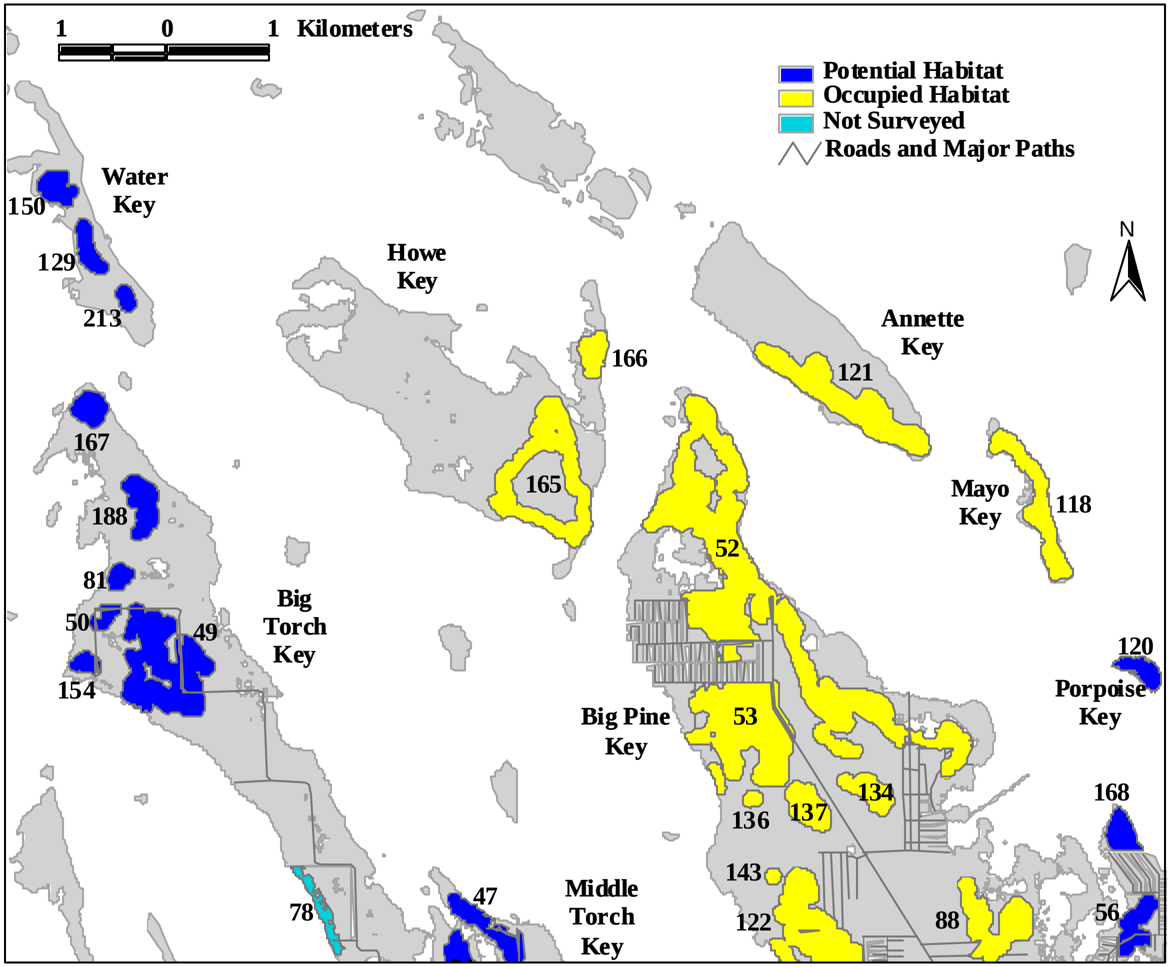

Fig. 2.45. Useable habitat (i.e., without scarified and paved areas) in occupied and potential Lower Keys marsh rabbit populations on Big Torch, Water, Howe, Annette, Mayo, and Porpoise keys and portions of Middle Torch and Big Pine keys in surveys conducted 2001–2003. An area was considered to be occupied if fecal pellets were discovered in ≥1 survey during the study period.

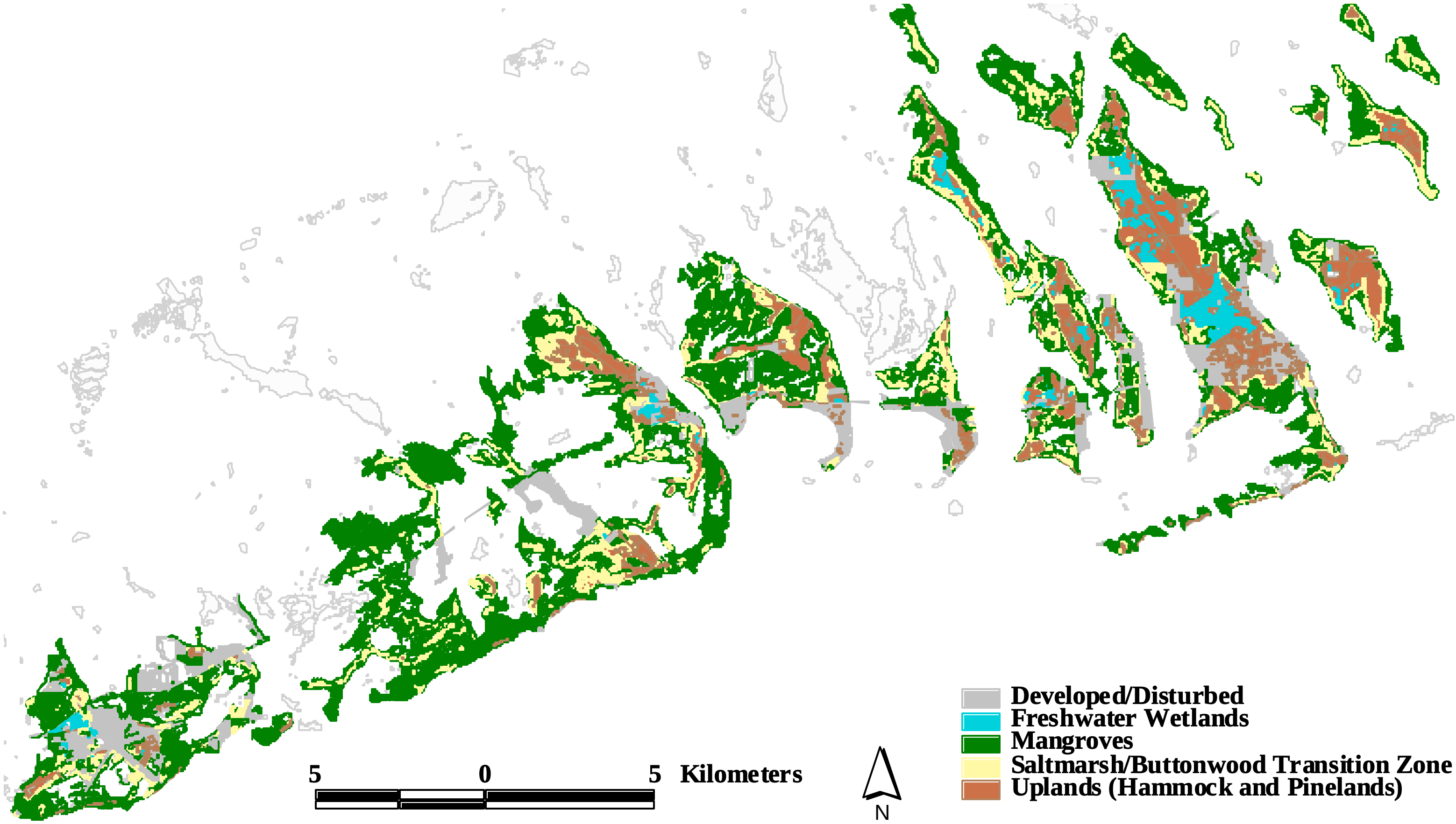

Fig. 2.46. Natural vegetation and developed/disturbed land on keys with occupied or potential Lower Keys marsh rabbit habitat in the Lower Keys of Florida, USA, from 2001–2003. Lower Keys marsh rabbits are more likely to disperse through natural vegetation types (i.e. freshwater wetlands, mangroves, saltmarsh/buttonwood transition zones, hammocks, and pinelands) rather than developed or disturbed areas.

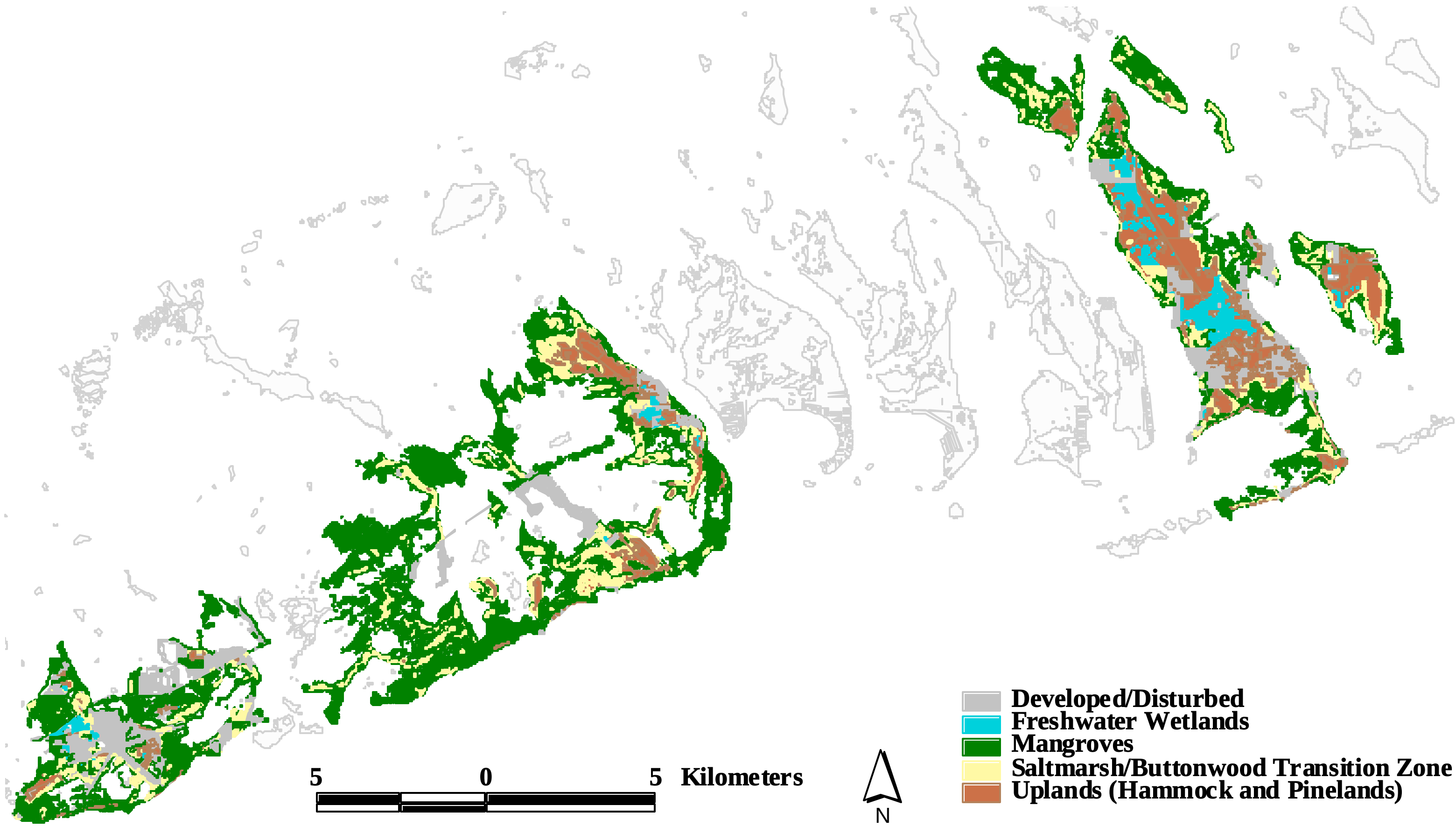

Fig. 2.47. Areas that could be used for dispersal by Lower Keys marsh rabbits in 2001–2003 without crossing channels between islands, assuming that developed and disturbed lands do not act as a barrier to dispersal. Lower Keys marsh rabbits are more likely to disperse through natural vegetation types (i.e. freshwater wetlands, mangroves, saltmarsh/buttonwood transition zones, hammocks, and pinelands) rather than developed or disturbed areas.

One hundred and eighteen unoccupied potential habitat patches totaling 277.9 ha were found during my study (Table 2.7). It should be noted that LKMRs were later reintroduced to 3 of these patches (12.3 ha) on Little Pine Key (Fig. 2.27, Chapter III). As in the previous surveys, LKMRs were absent from the northern portion of Sugarloaf Key, and there was a large gap in the LKMR's distribution between Big Pine Key and Sugarloaf Key (Figs. 2.23–2.26). Sixty patches of unoccupied potential habitat occurred in this gap (143.7 ha). Thirty-six of the unoccupied patches were visited ≥2 times during my study (Figs. 2.29–2.33). The median patch size was 1.4 ha with an inter-quartile range of 0.7–3.2 ha.

Local Populations

Nine rabbits (7 male, 2 female) were tracked ≥30 times over the course of ≥5 months (Table 2.8). The mean modified MCP range was 1.2 ha. The radius of a circular range of 1.2 ha would be approximately 60 m. Thus, 60 m was used as the buffer distance around patches. Patches 82, 83, 96, 113, and 131 were considered unsuitable for rabbits and were excluded from the analyses. Patches 113 and 131 were rendered unsuitable by human development, and the other patches either lacked escape cover or herbaceous ground cover.

Combining patches with overlapping buffers or buffers within < 2 m resulted in 144 OPLPs (Figs. 2.34–2.40, Appendix B). Fifty-six of these OPLPs were occupied by LKMRs, 80 were unoccupied, and 8 were not surveyed. Twenty-six percent of OPLPs contained >1 patch (range 1–11). When only the OPLPs included in the previous surveys were considered, there has been a net decrease of 8 occupied local populations (Table 2.9). Once roads and scarified areas were removed, the total useable habitat within the potential local populations amounted to 2,172.5 ha, 1,271.6 ha of which were occupied by LKMRs at least once during the study period (Fig.s. 2.36, 2.40–2.45). Including just the constituent patches (i.e. excluding buffers), the median amount of habitat/OPLP was 2.4 ha (inter-quartile range 1.1–5.3 ha, range). With buffers included, the median amount of useable habitat/OPLP was 8.2 ha (inter-quartile range 4.8–15.7 ha).

Dispersal Habitat

All areas of natural vegetation on all keys with OPLPs were encompassed by the 2,050-m cost grid (Figs 2.46). When only occupied local populations were included in the analyses, dispersing LKMRs still had access to all or most of the natural vegetation on each key with occupied populations. Exceptions included the extreme southern end of Big Pine Key and the extreme northern end of Sugarloaf Key, which fell outside of the grid. If rabbits recolonized potential habitat within the grid, LKMRs would be able to access all areas of natural vegetation in a stepping-stone manner (Fig. 2.47).

DISCUSSION

Comparison with Previous Surveys

Considering only areas identified in previous surveys, both the number of local populations and the number of occupied patches have declined throughout most the LKMR's range over the past 8 years.

Extirpated patches tended to occur on small outer islands or toward the periphery of the LKMR's range on occupied keys. The reasons for the extirpation of local populations differ from one location to the next, and both stochastic and deterministic factors may be involved.

Small populations face an increased risk of extinction from demographic and environmental stochasticity (Gilpin and Soule 1986, Caughley 1994). Given the small size of most LKMR populations, it is possible that both of these factors could have contributed to the observed extinctions. For example, the impact of Hurricane Georges in 1998 may be at least partially responsible for some extirpations. The storm surge reached 2.5 m on the southeastern portion of Big Pine Key (R. R. Lopez, Texas A&M University, personal communication), and P. A. Frank (USFWS, unpublished data) noted that several patches on Boca Chica, Geiger, the Saddlebunch, and Sugarloaf keys received complete overwash. In addition to direct mortality from the storm, it is possible the hurricane altered some areas enough to make the vegetation temporarily or permanently unsuitable for rabbits. Hurricane impacts may explain why the borders of some patches were mapped differently in the current and previous surveys.

Deterministic factors certainly contributed to some extirpations. Two patches on Big Pine Key were destroyed by mowing and development, respectively. In addition, invasive exotic plant species may have rendered patch 103 on Saddlehill Key unsuitable for rabbits. Exotic predators may have played a role as well. Free-ranging cats are common in the Lower Keys and have been known to prey on LKMR (Howe 1988, Forys 1995). Some of the extirpated patches, such as 11 and 13 on Geiger Key, are in close proximity to human development and are frequented by cats (personal observation; P. A. Frank, USFWS, unpublished data). Predation by native and exotic species is discussed later in this thesis (Chapter IV). It is likely that some local extinctions resulted from the interaction of multiple factors. Patch 56, for example, was impacted by Hurricane Georges and is in an area frequented by free-ranging cats (personal observation).

I was able to document the extirpation and recolonization of LKMR habitat patches over the 2-year study. Forys (1995) also documented extinction-colonization dynamics in the LKMR metapopulation. Local extinctions are part of the normal dynamics of classic metapopulations (Levins 1969, 1970). However, many of the areas from which rabbits have been extirpated over the past several years are unlikely to be recolonized without human intervention. For instance, suburban development may isolate potential populations 11 on Geiger Key and 56 on Big Pine Key from neighboring rabbit populations. Even if these areas could be artificially recolonized, their isolation and proximity to human development would make their persistence unlikely. Dispersal to areas south of U. S. Highway 1 on Big Pine Key may be hindered by development along the U. S. Highway 1 corridor and the Sands subdivision. Though LKMRs are excellent swimmers (Tomkins 1935), the physical isolation of small islands such as Munson, Porpoise, and Saddlehill keys reduces the chance of recolonization. If rabbits cannot naturally recolonize the extirpated patches, the sites are effectively removed from the LKMR metapopulation. Just as local populations with smaller numbers of individuals are more likely to go extinct (Gilpin and Soule 1986, Pimm et al. 1988), a reduction in the number of potential local populations increases the chance that the entire metapopulation will become extinct (Hanski 1998).

In addition to the observed decrease in the number of occupied sites, another concern for the LKMR is a possible reduction in rabbit density throughout occupied habitat, even in consistently-occupied areas. In 2002, E. A. Forys (Eckerd College, personal communication) noted that fecal pellet densities had declined in many of the patches since 1995, suggesting a decline in the density of individuals. Such a decline would increase the likelihood of local extinction through the factors described above. Forys's observation also underscores the need for monitoring at the local as well as the landscape scale. To examine trends at both of these scales, the USFWS and Texas A&M University are currently working on a long-term monitoring protocol. Given the cryptic nature and crepuscular/nocturnal habits of the rabbit, the monitoring protocol will likely use fecal pellets as an index for patch occupancy and rabbit density. I suggest that the monitoring occur at least once per year, probably during the dry season when pellets persist longer and are easier to see.

New Patches

It is unlikely that newly-documented patches represent an expansion of LKMR populations. Rather, the new patches represent an expansion of the area searched for fecal pellets. There may be other patches that have yet to be identified. For example, the Knockemdown Keys, north of Summerland Key, deserve more attention, as do areas along roadsides similar to patch 228.

It is possible that some of the smaller, new occupied patches may have been population sinks (Pulliam 1988) or stop-over sites for dispersers. Unfortunately, it can be difficult to identify sinks in a metapopulation with small, patchily-distributed populations due to the confounding effects of demographic and environmental stochasticity (Van Horne 1983). Alternatively, these areas might indicate that LKMRs use certain vegetation types more often than expected. Marsh rabbits have shown variability in their habitat use, and our understanding of LKMR habitat requirements may be incomplete. This study noted LKMRs using patches of lead tree adjacent to mesic grasslands, pinelands adjacent to freshwater wetlands, and vegetation along roadsides. *Sylvilagus palustris paludicola* has been known to use hammocks, agricultural fields, and roadsides (Carr 1939, Schwartz 1952, personal observation), and I have observed *S. p. paludicola* foraging near thick vegetation along canals in central Florida. Upland habitat might prove especially important in the wet season, when freshwater wetlands become inundated. Given the uncertainty in LKMR habitat use, particularly at night, new areas of occupied and potential habitat may still need to be identified. Future research could involve determination of the habitat used by rabbits at night, when they are most active (Blair 1936), and could attempt to elucidate relationships between habitat variables and demographic parameters (e.g., survival and productivity; Van Horne 1983, Garshelis 2000). This research could be used to find additional areas of potential habitat, to refine the selection process for reintroduction sites, and to improve habitat restoration or enhancement efforts. Information on movements and habitat use also should be gathered to refine the delineation of local populations, as the current buffer distance represents only a testable hypothesis.

Dispersal Habitat

If all potential habitat were occupied and human development did not act as a barrier to dispersal, dispersing LKMRs would have access to nearly all of the undeveloped land area on the major islands in the Lower Keys. Human development probably acts as an impediment to dispersal, but whether it acts as a complete barrier is unknown. Corridors of native vegetation connect most populations to their neighbors. However, the southern portion of Big Pine Key may be isolated by development along the U. S. Highway 1 corridor, and patches 31 and 32 are separated by development from most neighbors.

The ability of LKMRs to disperse across channels between larger keys is unknown. Marsh rabbits are excellent swimmers (Tomkins 1935, Blair 1936) and have been found on small outer islands in both the Upper and Lower Keys (Schwartz 1952, Forys 1995). However, LKMRs apparently have failed to recolonize larger islands between Big Pine and Sugarloaf keys. Estimates of gene flow among existing LKMR populations might elucidate how often and how far LKMRs are willing to swim between keys (see Chapter IV).

MANAGEMENT IMPLICATIONS

The number of LKMR local populations appears to have declined over the past 8 years. Stemming or reversing this subspecies' decline will require active management at both the population and landscape scales. Local scale management should include identification and removal of deterministic threats (e.g., exotic predators) and improving the quality and, where possible, size of existing habitat patches. Landscape scale management should include acquisition and protection of occupied and potential habitat, reintroductions to suitable habitat, and perhaps translocations to facilitate gene flow between isolated populations. These management actions are discussed in more detail later in this thesis (Chapter IV).

CHAPTER III

REINTRODUCTION

INTRODUCTION

Translocation is the capture of wild individuals or populations in one place and relocation into another within the species' range (International Union for the Conservation of Nature and Natural Resources/Reintroduction Specialists Group [IUCN/RSG] 1998). A subset of translocation is reintroduction, "the attempt to establish a species in an area which was once part of its historical range, but from which it has been extirpated or become extinct" (IUCN/RSG 1998:6). A reintroduction is considered successful if it results in the establishment of a self-sustaining population (Scott and Carpenter 1987, Griffith et al. 1989, Kleiman et al. 1994, but see Seddon 1999).

Reintroduction has become an increasingly common practice in wildlife conservation (Kleiman et al. 1994, IUCN/RSG 1998, Fischer and Lindenmayer 2000). Past reintroduction efforts for a variety of taxa, however, have often ended in failure and have been criticized for their lack of rigorous methodology and adequate monitoring (Short et al. 1992, IUCN/RSG 1998, Fischer and Lindenmayer 2000). Consequently, there have been several attempts to provide guidelines that can be used by managers to increase reintroduction success (Nielsen 1988, Kleiman et al. 1994, IUCN/RSG 1998). Among these guidelines were

1. There must be adequate knowledge of the target species' ecology (May 1991, IUCN/RSG 1998).
2. The current status and distribution of the species must be known (Nielsen 1988).
3. Potential release sites should be evaluated to ensure there is a sufficient amount of protected potential habitat and the reasons for the species' decline have been removed (Griffith et al. 1989, Kleiman et al. 1994).
4. A well-documented methodology must be developed for all steps of the reintroduction (Scott and Carpenter 1987, Nielsen 1988).
5. A pilot study should be conducted to gain important knowledge and experience for future reintroductions (Nielsen 1988).
6. Reintroductions should be monitored over both the short and long term (Dodd and Siegel 1991, IUCN/RSG 1998), as both the establishment phase and the long-term persistence of established populations must be evaluated (Armstrong et al. 1999).
7. The feasibility of translocation should be assessed based on the results of the pilot study and monitoring (Nielsen 1988, Hein 1997).

The USFWS (1999) proposed reintroduction as a recovery strategy for the LKMR, a subspecies endemic to the Lower Keys of Florida. Listed as federally endangered in 1990 (USFWS 1990), the

LKMR faces the threat of extinction due to a combination of deterministic and stochastic factors. Lower Keys marsh rabbits exist as a metapopulation in patches of saltmarsh/buttonwood transition zone, freshwater wetlands, and coastal beach berm habitat (Forys and Humphrey 1996, Chapter III). The USFWS (1999) cited the loss and fragmentation of this habitat from development as the primary reason for the decline of the subspecies. Other deterministic threats to LKMRs have included mortality from cats and vehicles, which accounted for over half of all LKMR mortality in studies by Forys and Humphrey (1999) on Boca Chica Key. Additionally, Forys et al. (1996) suggested fire and feral hogs (*Sus scrofa*) may have played a role in the extirpation of some populations, and Howe (1988) proposed hunting as a possible historical cause of the rabbit's decline.

Small populations face a greater risk of extinction due to environmental and demographic stochasticity, and r-selected species are particularly susceptible to the latter (Gilpin and Soule 1986, Caughley 1994). Thus, small, patchily-distributed LKMR populations face an increased chance of local extinction, particularly if human development blocks dispersal between patches. Deterministic factors such as habitat loss and human-influenced mortality exacerbate these problems by making populations even smaller and more isolated. A population viability analysis model (PVA; Forys and Humphrey 1999) suggested LKMRs could be extinct within 50 years without intervention.

Because metapopulations with a larger number of local populations are more likely to persist over time (Den Boer 1968, Hanski 1998), reintroduction represents an important way to reduce the risk of extinction for this species. Some of the reintroduction criteria mentioned earlier had already been met for the LKMR at the time of my study. For instance, Forys (1995) and Forys et al. (1996) studied the population dynamics of LKMRs on Boca Chica Key and the metapopulation dynamics throughout the LKMR's range. My efforts to update the distribution of the LKMR were being conducted concurrently with the reintroduction planning (Chapter II), and the USFWS (1999) had suggested some potential release sites. Some reintroduction criteria, however, had not been addressed. Source populations still needed to be identified, and no translocation methodology and post-release monitoring protocols had been established for the LKMR. Historically, translocation and introduction have been common practices for lagomorphs (Clapp et al. 1976, Whatmough 1995, Calvete et al. 1997). Until recently, however, few of these efforts involved rigorous methodology and monitoring (Calvete et al. 1997, Moreno and Villafuerte 1997, Letty et al. 2000, Swanson 2002, Williams et al. 2002).

Therefore, the objective of this research was to conduct a pilot study to

1. Establish protocols for LKMR translocation, including the capture, transport, and release of individuals.
2. Reintroduce adult or subadult LKMRs to multiple patches of habitat.
3. Evaluate the short-term success of translocations through post-release monitoring. Short-term criteria for success included survival equal to or better than a control group, fidelity to release sites, and

evidence of reproduction. This thesis only addresses short-term monitoring, as a long-term monitoring plan was still being refined at the time of writing.

4. Provide recommendations that could lead to the development of a reintroduction plan for this subspecies.

Two pilot reintroductions were conducted. The second reintroduction was meant to be a limited initial release of a few individuals, and the USFWS intended to augment the population over time.

STUDY AREA

Little Pine Key, a 325-ha island in the eastern portion of the rabbit’s historic range, was chosen to be the first reintroduction site (Fig. 3.1). This island was part of the National Key Deer Refuge managed by the USFWS, and it also was included in the Florida Keys Wilderness Area, part of the National Wilderness Preservation System designated by the U. S. Congress through the Wilderness Act of 1964. Areas with thick cover of plant species common to occupied rabbit habitat were found in both the western and southeastern portions of the island (Fig. 3.1). Potential habitat patches were composed of both grassy saltmarsh and buttonwood transitional vegetation types. Gulf cord grass, a significant predictor of patch occupancy (Forys 1995), was common in patches 142, 159, and 99. Totaling 13 ha, these sites provided 2 general release areas separated by >1 km. Furthermore, a narrow buttonwood transitional area surrounding the island’s central uplands could provide additional areas for rabbits to colonize over time. Roads, human habitations, and feral cats were absent from the island. Moreover, feral hogs, which had degraded much of the potential rabbit habitat, were removed by the USFWS in the early 1990s (T. Wilmers, Wildlife Biologist, U.S. Fish and Wildlife Service, personal communication).

Two patches, 49 and 79, in the northern portion of Big Torch Key, a 604-ha island, were chosen as a second reintroduction site (Fig. 3.2). Although the patches were bisected by a road, they contained 19.9 ha of potential habitat, much of which was on public land, and were in close proximity to other neighboring habitat patches. The patches were composed of a mixture of freshwater hardwoods, freshwater marsh, and saltmarsh/buttonwood transition zone vegetation. Only 2 human residences were present on the entire northern portion of the island, and no sign of cats was seen during the distribution survey (Chapter II). Establishing rabbits on Big Torch Key would meet 1 of the recovery criterion set forth in the subspecies’ Recovery Plan, which calls for stable populations on $\geq$5 keys connected to U. S. Highway 1 (USFWS 1999).

Due to poor historical records for this subspecies, the causes of the extirpation of the LKMR are difficult—if not impossible—to determine in some areas. This is true for Big Torch Key, where the reasons for the extirpation are uncertain but may have included hunting (J. D. Lazell, The Conservation Agency, personal communication) and/or hurricanes. Current residents in the area are probably less likely to poach rabbits than in the past, particularly given the legal protection afforded to the animals. For example, the endangered Key deer was nearly extirpated from the keys by the late 1940s due to over-

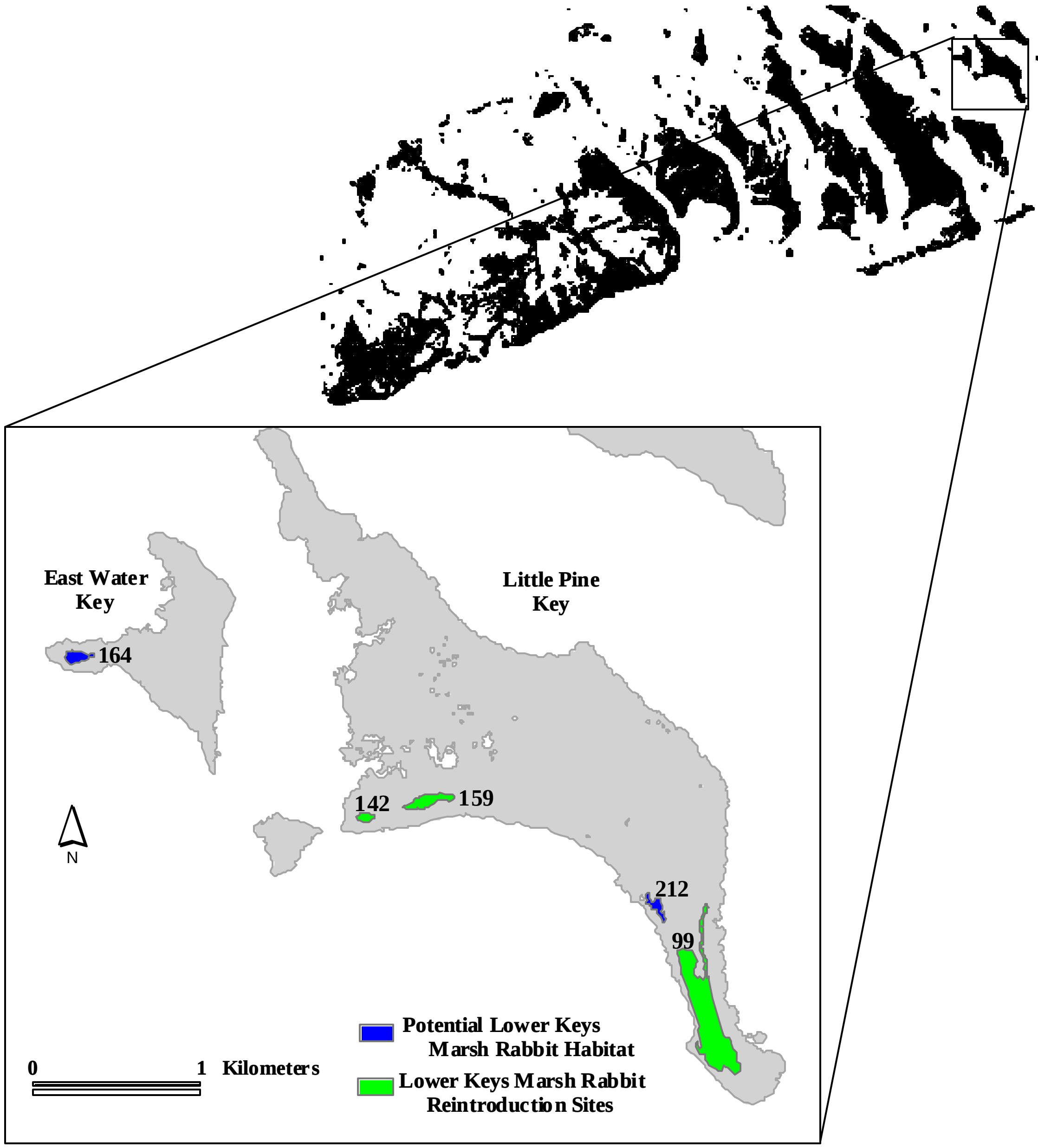

Fig. 3.1. Three patches of potential habitat on Little Pine Key were chosen as reintroduction sites for the Lower Keys marsh rabbit in 2002. Little Pine Key is within the eastern portion of the rabbit's range in the Lower Keys of Florida, USA. Each patch of potential habitat was given an identification number.

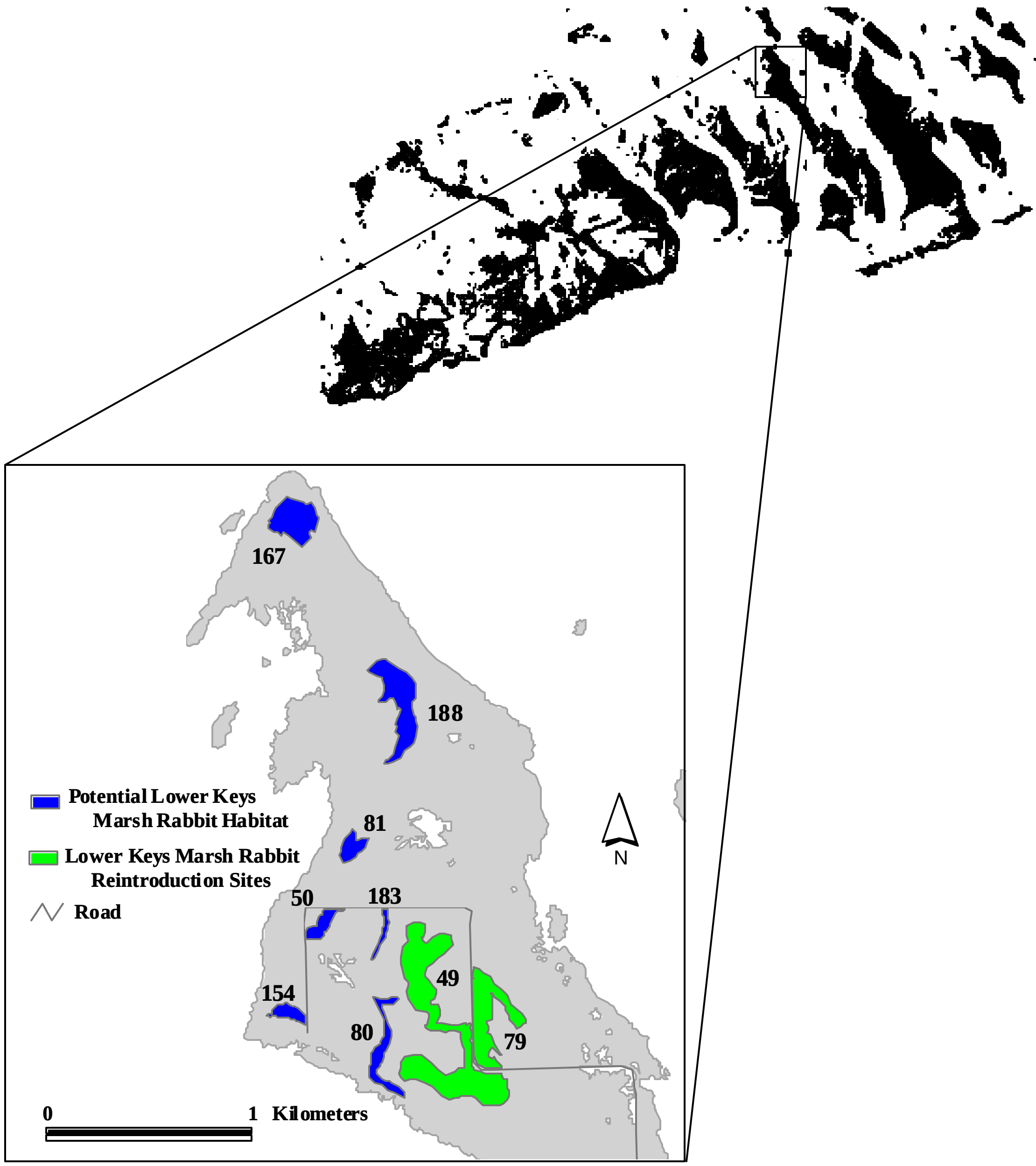

Fig. 3.2. Two patches of potential habitat on Big Torch Key were chosen as the second reintroduction site for the Lower Keys marsh rabbit in 2002. Several neighboring patches of habitat were present on the island. Big Torch Key is located in the east-central portion of the rabbit's historic range in the Lower Keys of Florida, USA. Each patch of habitat was given an identification number.

hunting (Dickson 1955, USFWS 1999), but deer are rarely poached at present (R. R. Lopez, Texas A&M University, personal communication). Plus, when reasons for an extirpation cannot be determined, a well-monitored reintroduction can be viewed as an adaptive management experiment in which unpredicted threats are identified and addressed (Engelhardt et al. 2000). Thus, although this reintroduction site carried more risk than Little Pine Key, it was determined that the benefit of facilitating the colonization of the entire northern end of Big Torch Key was sufficient to proceed.

METHODS

Acquisition of Individuals and Translocation

Because this research was a pilot study conducted on a limited scale, translocation of wild-caught individuals was chosen over the establishment of an *in-situ* or *ex-situ* captive breeding program. Translocations of wild-caught individuals tend to be more successful than translocations using individuals from *ex-situ* captive breeding (Griffith et al. 1989, Snyder et al. 1996, Fischer and Lindenmayer 2000). Precautions were taken to minimize the impact of the reintroduction on source populations. During the 2001–2002 portion of the distribution survey (Chapter II), areas were considered to be potential source populations if they were (1) part of a closely-spaced, well-connected network of occupied local populations, (2) a local population with a moderate to high density of fecal pellets, or (3) a local population with 1 of the largest areas of suitable habitat in the metapopulation. Within each source population, the number of rabbits to be removed was determined in coordination with USFWS staff based on the percentage of the habitat in which trapping occurred, the minimum-number-known-alive (MNKA) in this habitat, and the sex and age ratios of the trapped rabbits.

The MNKA is a conservative method to estimate abundance because it produces estimates that are negatively biased (Nichols and Pollock 1983, Slade and Blair 2000). Given the endangered status of the species, a conservative approach was preferable to indirect abundance estimates from fecal pellet counts. Exploratory trapping efforts in October and November 2001 indicated that the number of rabbits per habitat patch and the probability of capture were both too low for mark-recapture and catch-per-unit-effort models to yield reliable estimates (Otis et al. 1978). The cryptic nature of the LKMR and its tendency to remain in thick cover prevented the use of line transect or spotlight counts.

Source populations were identified throughout the LKMR's range to maximize the genetic diversity of the founder population. Sampling throughout the historic range of the species could raise concerns of outbreeding depression in the founder population (Storfer 1999). However, outbreeding depression appears to be uncommon in mammals (but see Marshall and Spalton 2000) and usually occurs when the geographic separation between populations is large (Ralls et al. 2001). Outbreeding depression was considered unlikely because the LKMR's historic range is relatively small and lacks significant latitudinal variation.

Rabbits were trapped and handled in accordance with Animal Use Protocol #2001-109, as approved by the Texas A&M University's Institutional Animal Care and Use Committee. Rabbits were captured in 60-cm x 18-cm x 18-cm 2-door Tomahawk traps (Tomahawk Live Trap, Tomahawk, Wisconsin). Because of a problem with raccoon predation, all traps were wrapped with 12.7-mm hardware cloth. After further predation, the bodies of the traps were reinforced with 6.4-mm lauan plywood, and the doors were reinforced with 6.4-mm hardware cloth (Fig. 3.3). The efficacy of these modifications was tested by baiting closed traps with cat food and placing the traps in areas frequented by raccoons.

In areas with thick cover of clump-forming grasses or Cyperaceae such as gulf cordgrass, saltmarsh fringe-rush, and senescent saw grass, LKMRs travel through tunnels in the vegetation (Howe 1988). In these areas, un-baited traps were lined with grasses and placed in the tunnels, especially those with fresh fecal pellets. Traps were covered with grasses and other vegetation to simulate a natural tunnel.

Many areas of LKMR habitat lack thick, tunnel-forming groundcover, particularly areas dominated by seashore dropseed, buttonwood, and small trees and shrubs. In these areas, drift fence arrays were erected in an attempt to force rabbits to travel into traps. Drift fences were originally constructed from 7.62-m x 0.46-m rolls of 1.27-cm chicken-wire netting but were later constructed from 7.62-m x 0.3-m netting. Chicken-wire netting was cut to 7.62-m lengths to provide more flexibility in the design of the drift fence and to promote ease of rolling and carrying. At each end of the fence, 0.5-m lengths of 1.27-cm rebar were attached with cable ties. Additional pieces of rebar or natural materials (e.g., branches, rocks, etc.) were used as necessary to keep the fence upright, alter its shape, and ensure the fence remained flush to the ground.

Drift fences and traps were set in a variety of arrays depending on the nature of the vegetation. The most common pattern was an "X" with 4 fence lines radiating from a central trap (Fig. 3.4). Other arrays included straight or meandering fence lines that conformed to vegetation patterns in the habitat or combinations of "X" and meandering patterns. The number of 7.62-m segments employed depended on the nature of the habitat.

In addition to the above methods, exploratory trapping was conducted from November 2001–January 2002 to find a suitable bait for the traps. Baits included apple, banana, carrot, radish, spinach, wheat bread, parsley, and alfalfa. Domestic rabbit urine was applied to some traps (Young and Henke 1999), and vanilla extract was used in others (M. Walker and D. Holt, Mississippi State University, personal communication).

Traps were set in the late afternoon or evening and checked early the next morning. Trapping generally occurred 5–6 nights per week. Traps were tied open during the day and on days when no trapping took place to keep rabbit travel passages open and to allow rabbits to become accustomed to passing through traps.

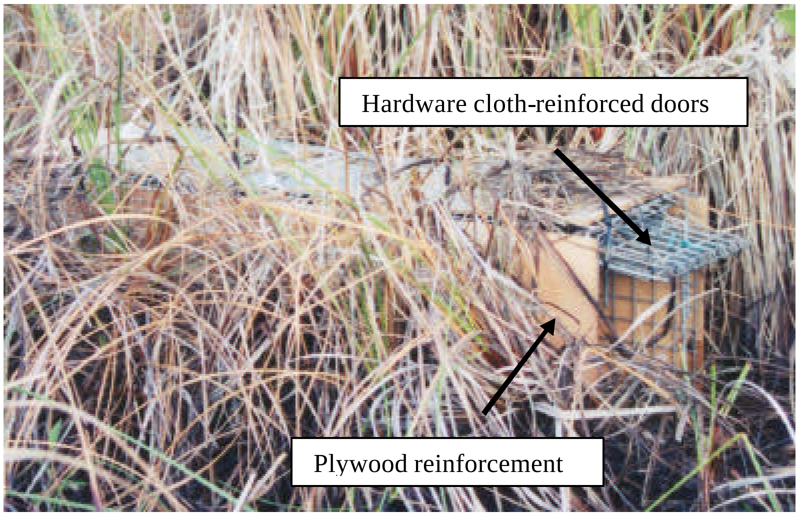

Fig. 3.3. Two-door Tomahawk trap modified with 6.4-mm lauan plywood on the body and 6.4-mm hardware cloth on the doors.

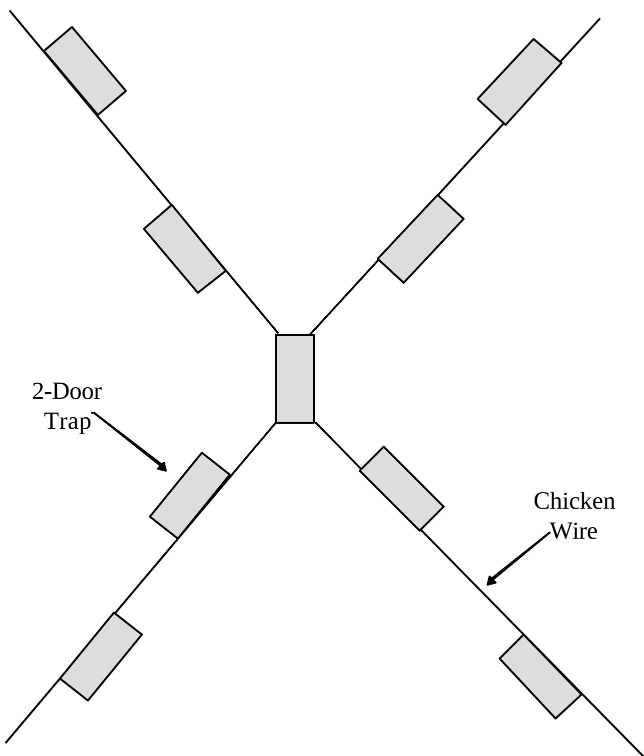

Fig. 3.4. View from above of typical "X" drift-fence array used to capture Lower Keys marsh rabbits from 2001–2002 in the Lower Keys of Florida, USA.

Captured rabbits were transferred to cotton pillowcases and carried to the work vehicle. Rabbits were handled within the work vehicle to prevent escape and to provide air conditioning to guard against the rabbit overheating. A small cotton hood was placed over the rabbit's head to cover the eyes and calm the individual. Rabbits were weighed in the pillowcase using a Pesola medio scale (Pesola AG, Baar, Switzerland). The sex of each LKMR was determined using the criteria described by Dimmick and Pelton (1994). Rabbits were classified as adults using 2 criteria: (1) appearance of sexual organs (Dimmick and Pelton 1994) and (2) weight >1,000 g, within 3 standard deviations of the mean for adults as determined by Forys (1995). Rabbits were individually marked by subcutaneous injection of a passive integrated transponder tag (Biomark, Boise, Idaho, USA). Hair samples were collected for later genetics work. Female rabbits were checked for signs of lactation or pregnancy. Juvenile and smaller subadult rabbits were released at the site of their capture. Adult rabbits and older subadults were (1) released at the site of their capture, (2) given a collar with a radio transmitter and released as a control group, or (3) given a collar with a radio transmitter and translocated to a release site. Only individuals with a mass >800 g were fitted with collars. Initially, 25-g transmitters attached to a neoprene-impregnated collar (Telemetry Solutions, Concord, California, USA) were used. These transmitters had a mortality signal and a battery life of approximately 365 days. During the latter half of the study, a long battery life was deemed unnecessary, and rabbits were affixed with 7-g transmitters attached to a cable tie collar or nylon collar (Advanced Telemetry Systems, Isanti, Minnesota, USA). These transmitters had a battery life of approximately 170 days with no mortality signal. Cable-tie collars were modified using Safe-Ty Low Profile Ties (Thomas and Betts, Memphis, Tennessee, USA) to allow the collars to remain round even at small neck sizes.

Rabbits were translocated individually in 58-cm x 37-cm x 29-cm plastic pet carriers (Drs. Foster and Smith, Rhinelander, Wisconsin, USA) lined with a thick layer of grasses. Individuals were transported in trucks and by boat to the release area. Translocated LKMRs were given a hard rather than a soft release (i.e., no supplemental food was provided, and individuals were not kept in an acclimation pen). Same-sex individuals were usually released in different areas to account for the spacing behavior exhibited by the species (Forys 1995).

Post-release Monitoring

Rabbits were usually tracked to their forms once per day for 3 days following their release and $\geq$3 times per week for the next 2 months. After this time, translocated LKMRs were usually tracked 1–2 times per week until either the rabbit died or the transmitter failed. When mortalities occurred, time of death was estimated and the area within a 5-m radius of the radio collar was searched in an attempt to determine cause of mortality. Rabbits (controls) in the source populations were tracked during the same time period as the translocated rabbits. Individuals were tracked to their daytime forms using a receiver from Advanced Telemetry Systems and a 3-element yagi antenna (AF Antronics, Urbana, Illinois, USA).

Each rabbit's location was marked on printouts of DOQQs or using a Garmin 12 hand-held global positioning system (Garmin, Olathe, Kansas, USA). Spatial locations were recorded in a geographic information system using ArcView (Version 3.2) (Environmental Systems Research Institute, Redlands, California, USA).

The endangered status of the LKMR and the desire to protect source populations necessitated reintroductions limited to few individuals. This made comparisons of survival curves (e.g., Kaplan-Meier estimator [Kaplan and Meier 1958, Pollock et al. 1989]) difficult due to a lack of statistical power. Therefore, the proportion of individuals surviving >5 months were compared between the translocated rabbits and control group.

Fidelity to the release area occurred if translocated rabbits established ranges inside the intended habitat patches. Fidelity also was examined by measuring the mean distance from the point of release to all telemetry locations after a rabbit established a stable range. An individual was considered to show excellent site fidelity if the mean distance was $\leq$ the diameter of an average LKMR range. This diameter was estimated to be 120 m (Chapter IV), although this estimate does not include night locations and is probably negatively biased.

To avoid disturbance to nesting females or accidental destruction of nests, the presence of juvenile fecal pellets was used as an indicator of reproduction in the release areas. Release areas were walked once every 2 weeks in search of juvenile fecal pellets. Juvenile pellets can be distinguished from adult pellets by size (Forys 1995). Forys (1995) established a relationship between LKMR pellet size and mass and constructed growth curves for the LKMR. When juvenile pellets were discovered in the release site, this information was used to estimate the age of the rabbit.

RESULTS

Acquisition of Individuals and Translocation

One hundred and nine LKMR captures were made over 3,884 trap nights from October 2001–August 2002 (capture probability = 2.8%, or 1 rabbit every 35.6 trap nights) (Appendix C). These captures included 70 individuals from 13 occupied populations on 5 keys (Table 3.1, Appendix C). Incidental captures included 18 raccoons, 9 black rats (*Rattus rattus*), and 5 Florida box turtles (*Terrapene carolina*). Baits were used during 206 trap nights from October 2001–January 2002. Raccoons consumed most baits and became adept at stealing baits without being captured. Baited traps resulted in only 1 rabbit capture, a female LKMR captured in a trap baited with domestic rabbit urine.

Table 3.1. The number of individual Lower Keys marsh rabbits captured in 13 occupied populations on 4 keys from October 2001–August 2002. Data are arranged according to sex and age class.

Age class	Female	Male	Total
Adult	20	29	49
Juvenile	3	3	6
Subadult	5	10	15
Total	28	42	70

Table 3.2. Lower Keys marsh rabbits translocated to Little Pine Key in the Lower Keys of Florida, USA, in 2002. A passive integrated transponder (PIT) tag was used to individually mark rabbits. Individuals will be referred to by Rabbit Code throughout this chapter.

PIT tag number	Rabbit code	Sex	Age	Source population	Source key	Release patch	Date of release
42256C7946	A	Male	Subadult	29	Saddlebunch	159	25 Jan 2002
4225757535	B	Male	Adult	3	Boca Chica	159	29 Jan 2002
4225565F20	C	Female	Adult	29	Saddlebunch	159	31 Jan 2002
42256C6938	D	Male	Adult	29	Saddlebunch	142	31 Jan 2002
42286E5E1D	E	Female	Subadult	33	Sugarloaf	159	14 Mar 2002
4226092B08	F	Female	Adult	22	Boca Chica	159	26 Mar 2002
422F4B304F	G	Female	Adult	122	Big Pine	159	24 Oct 2002
42257C2452	H	Male	Adult	33	Sugarloaf	99	21 Mar 2002
4225413002	I	Female	Adult	22	Boca Chica	99	26 Mar 2002
4225716E16	J	Male	Subadult	8	Boca Chica	99	30 Mar 2002
4230370224	K	Female	Adult	162	Saddlebunch	99	03 Apr 2002
4230517704	L	Female	Adult	162	Saddlebunch	99	05 Apr 2002

Table 3.3. Lower Keys marsh rabbits translocated to Big Torch Key in the Lower Keys of Florida, USA, in 2002. A passive integrated transponder (PIT) tag was used to individually mark rabbits. Individuals will be referred to by Rabbit Code throughout this chapter.

PIT tag number	Rabbit code	Sex	Age	Source population	Source key	Release patch	Date of release
422F2D2602	M	Male	Adult	122	Big Pine	49	12 Jun 2002
422F4B304F	G	Female	Adult	122	Big Pine	49	25 Jun 2002
422F2F5576	N	Male	Adult	33	Sugarloaf	49	25 Jul 2002

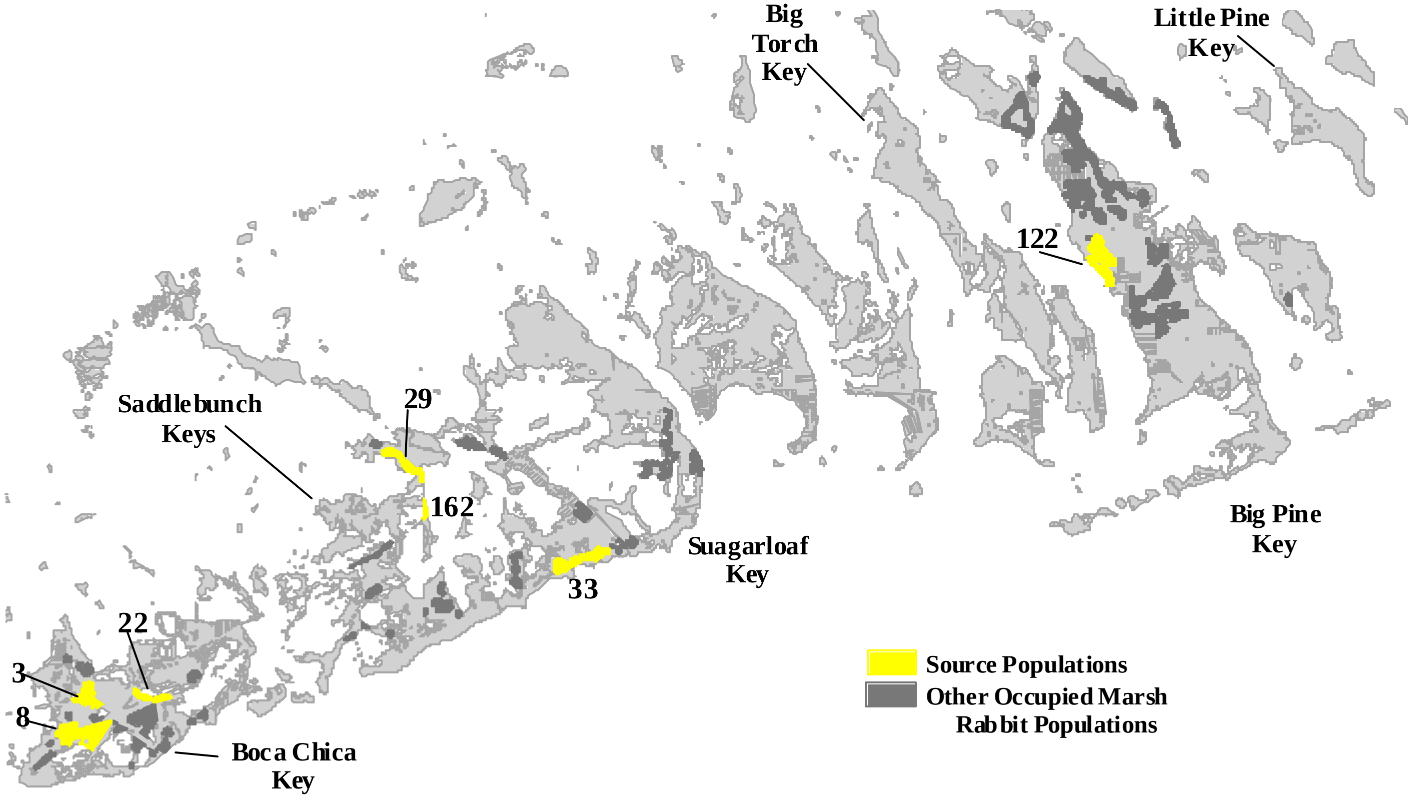

Fig. 3.5. Lower Keys marsh rabbits were translocated to Little Pine Key and Big Torch Key from 7 source populations located on 4 keys in the Lower Keys of Florida, USA, in 2002. Each Lower Keys marsh rabbit population was given an identification number.

Eleven captured rabbits had small patches of fur missing from the frontonasal region of the head, and 6 had small lacerations on or around the nasal region. Otherwise, there were no other injuries caused by the traps. Three trapped LKMRs were killed by raccoons. The first rabbit was killed in a trap on 27 November 2001 on Boca Chica Key, after which traps were modified with hardware cloth as described above. This modification worked until 13 February 2002, when several raccoons worked together to kill 2 rabbits in traps on the Saddlebunch Keys. After traps were modified with lauan plywood and additional hardware cloth, there were no additional mortalities in traps. Out of 108 captures, 1 rabbit in patch 52 on Big Pine Key died from unknown causes during handling.

Seven populations were used as sources for the reintroduction (Fig. 3.5). Within these populations, 67 LKMRs, including 61 adults and subadults, were trapped. Three of these populations were on Boca Chica Key, which had 36 patches of occupied habitat arranged in an estimated 16 local populations during the period from 2001–2003 (Chapter II). These populations were spaced fairly close together, and at the time of the study, rabbits could disperse easily from one population to another. Twenty adult and subadult rabbits were trapped in 3 populations, and 4 of these rabbits were translocated to Little Pine Key (Table 3.2). Trapping occurred in approximately 20% of the wetland habitat within the 3 populations.

Naval Air Facility, Key West, owns an antenna facility in the Saddlebunch Keys that contains 3 well-connected, occupied LKMR populations (Chapter II). Trapping occurred in habitat patches within 2 of these populations from January–April 2002, resulting in a MNKA of 23 rabbits, including 19 adults and subadults (Fig. 3.5). Four out of 6 juveniles captured in this study were trapped in these populations, and trapping in these areas yielded higher trap success than in other populations (7.9% or 1 rabbit for every 12.7 trap nights). Trapping occurred in approximately 40% of the patch area within 2 of the 3 populations. Five rabbits were translocated to Little Pine Key (Table 3.2).

On Sugarloaf Key, one of the largest patches of occupied habitat (patch size = 21.5 ha) was chosen as a source population (Fig. 3.5). Trapping efforts encompassed roughly half of the patch, and 14 adults and subadults were captured during 2 trapping periods (March 2002 and July–August 2002). Two rabbits were translocated to Little Pine Key, and 1 rabbit was moved to Big Torch Key (Tables 3.2–3.3).

Another of the largest occupied areas, with a patch size of 34.5 ha on Big Pine Key, was used as a source (Fig. 3.5). Trapping efforts covered roughly 20% of the patch. Ten individuals (5 adults) were captured from May 2002–June 2002, and 1 adult female and 1 adult male were translocated to Big Torch Key (Table 3.3).

In summary, 11 rabbits were translocated to Little Pine Key from 25 January 2002–05 April 2002 (Table 3.2). Seven rabbits were released at the western site, and five rabbits were released at the southern site (Table 3.2). Two males and a female were released on Big Torch Key from 12 June 2002–25 July 2002 (Table 3.3). The female was later recaptured and translocated to Little Pine Key on 24 October 2002 (see below). All translocated rabbits were given a letter code (e.g., Rabbit A, Rabbit B, etc.) (Tables 3.2–

3.3). There were no injuries or mortalities associated with transport. Fourteen rabbits were released at the site of their capture and monitored as a control group during the same time period as the translocated rabbits (Table 3.4).

Post-release Monitoring

Little Pine Key Reintroduction.-- In the southern release site, unidentified predators killed an adult female and an adult male 3 days and 10 days after their release, respectively. The mortalities occurred not far from the individuals' release sites in patch 99. One adult female's transmitter failed within 3 days of her release, and her fate was unknown. The remaining 9 rabbits on Little Pine Key were known to live for >5 months. One of these rabbits died 7 months after her release; no evidence of disease or injuries from predators was found (G.S. McLaughlin, National Wildlife Health Center, personal communication). The other 8 translocated LKMRs survived longer than the battery life of their transmitters and may still be alive. A collared rabbit was seen in the southern release site on 04 July 2003 (N. Perry, Texas A&M University, personal communication).

Telemetry locations of 7 of the 9 rabbits that lived > 10 days showed little displacement away from the release site (Fig. 3.6; e.g., Figs. 3.7–3.9). Of these 7, only Rabbit H, with a mean distance of 125 m (SD 133), had a mean distance exceeding 120 m from the release site. In patch 159, the rabbits exhibited spacing behavior almost immediately, with same-sex individuals showing only occasional overlap in the distribution of their form sites (Figs. 3.7–3.9). Rabbit A used both patch 142 and patch 159 (Table 3.2, Fig. 3.5). Spacing behavior also was evident for the females in patch 99, though the males showed some overlap of form site locations (Figs. 3.10–3.11).

Rabbit D and Rabbit E showed large displacements away from their release sites (Fig. 3.6). The male, Rabbit D, remained in his release site (patch 142) for 3 days and then established a range 500 m away in the eastern portion of patch 159. The subadult female, Rabbit E, remained close to her release site in patch 159 from 14 March 2002–05 April 2002, though she made a long-distance movement along the southern coast of the island from 19 March 2002–21 March 2002. From 9 April 2002–12 May 2002, the female progressively traveled (2 km) to the southern release area (patch 99), where she established a permanent range. The female stayed several weeks in patch 212 before proceeding to patch 99. From 25 April 2002–30 April 2002, the male joined the female in patch 212 before returning to his former range. On 14 May 2002, the male returned to patch 212. By 20 May 2002, the male had reached patch 99 and established an overlapping range with the female.

The first sign of reproduction on Little Pine Key was discovered when an adult female was found dead from unknown causes on 23 August 2002. Necropsy of the individual revealed placental scars and small amounts of milk in some mammary glands, suggesting the rabbit had recently weaned a litter (G.S. McLaughlin, National Wildlife Health Center, personal communication). Juvenile pellets were discovered in the western release area on 28 October 2002. Based on the size of the pellets, the rabbit was probably

3–4 months old. Bi-weekly surveys for juvenile pellets were stopped at this time, although, if seen, juvenile pellets were noted while tracking adults. Juvenile pellets from a rabbit <3-months old were found in the western release area on 22 January 2003, and juvenile pellets of a rabbit 3–4 months old were discovered in the southern release site on 27 March 2003.

Big Torch Key Reintroduction.-- Rabbit M was tracked until his signal was lost on 29 July 2002. An adult female, Rabbit G, was translocated to Big Torch Key on 25 June 2002. Her radio transmitter failed at the end of September 2002, but she was re-captured and moved to Little Pine Key on 24 October 2002 (see below). A second adult male, Rabbit N, was moved to Big Torch Key on 25 July 2002. This rabbit's signal could only be established intermittently. The rabbit's signal was lost from 31 July 2002–11 August 2002 and again from 14 Septemeber 2002–27 November 2002. The rabbit was last seen alive on 31 January 2003.

Table 3.4. Lower Keys marsh rabbits released at the site of their capture and radio-tracked as a control group from 25 January 2002–13 February 2003 in the Lower Keys of Florida, USA.

PIT tag number	Sex	Population	Key	Duration of tracking (days)	Reason to stop tracking
422873767B	Male	8	Boca Chica	276	Collar Failed
4225635412	Female	8	Boca Chica	96	Mortality
422554031C	Female	3	Boca Chica	293	Mortality
42257C2666	Male	3	Boca Chica	92	Mortality
4225523E75	Male	8	Boca Chica	154	Collar Failed
42257D217F	Male	8	Boca Chica	235	Collar Failed
42254C2F78	Male	33	Sugarloaf	294	Collar Failed
422F31447B	Male	162	Saddlebunch	163	Mortality
423052236A	Male	122	Big Pine	233	Collar Failed
42304D7610	Female	122	Big Pine	211	Collar Failed
422F2C0118	Male	122	Big Pine	6	Mortality
422F2A6C76	Female	33	Sugarloaf	212	Collar Failed
422F442714	Female	33	Sugarloaf	195	Collar Failed
42257C2452	Male	33	Sugarloaf	182	Collar Failed

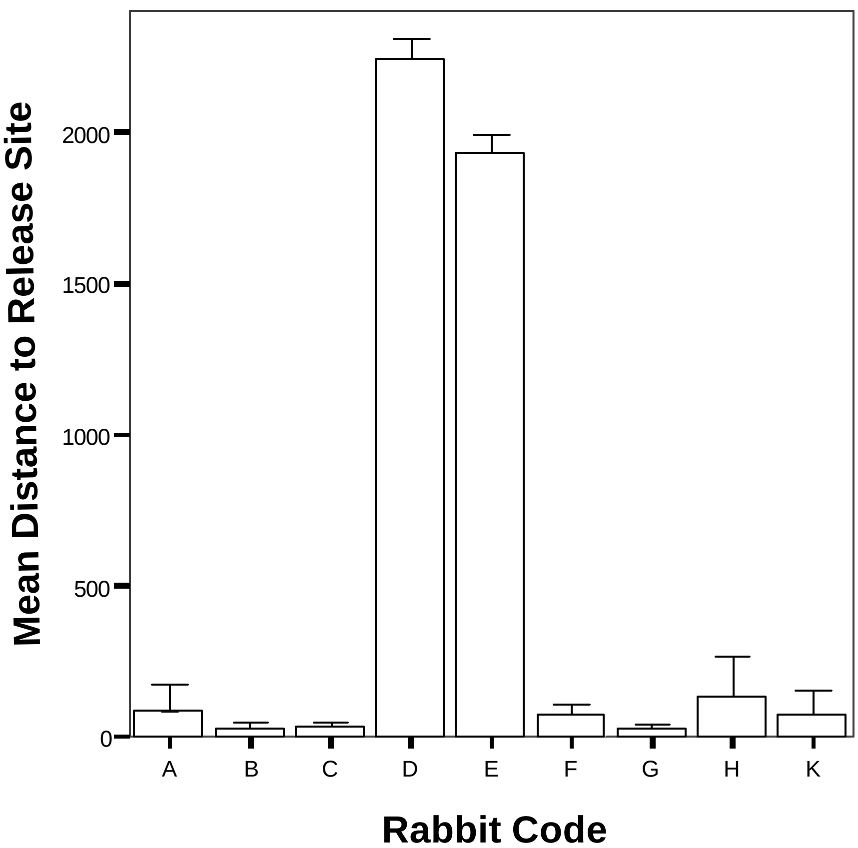

Fig. 3.6. Mean distance to release site of radio telemetry locations in the established ranges of translocated Lower Keys marsh rabbits on Little Pine Key. Error bars represent 1 standard deviation from the mean.

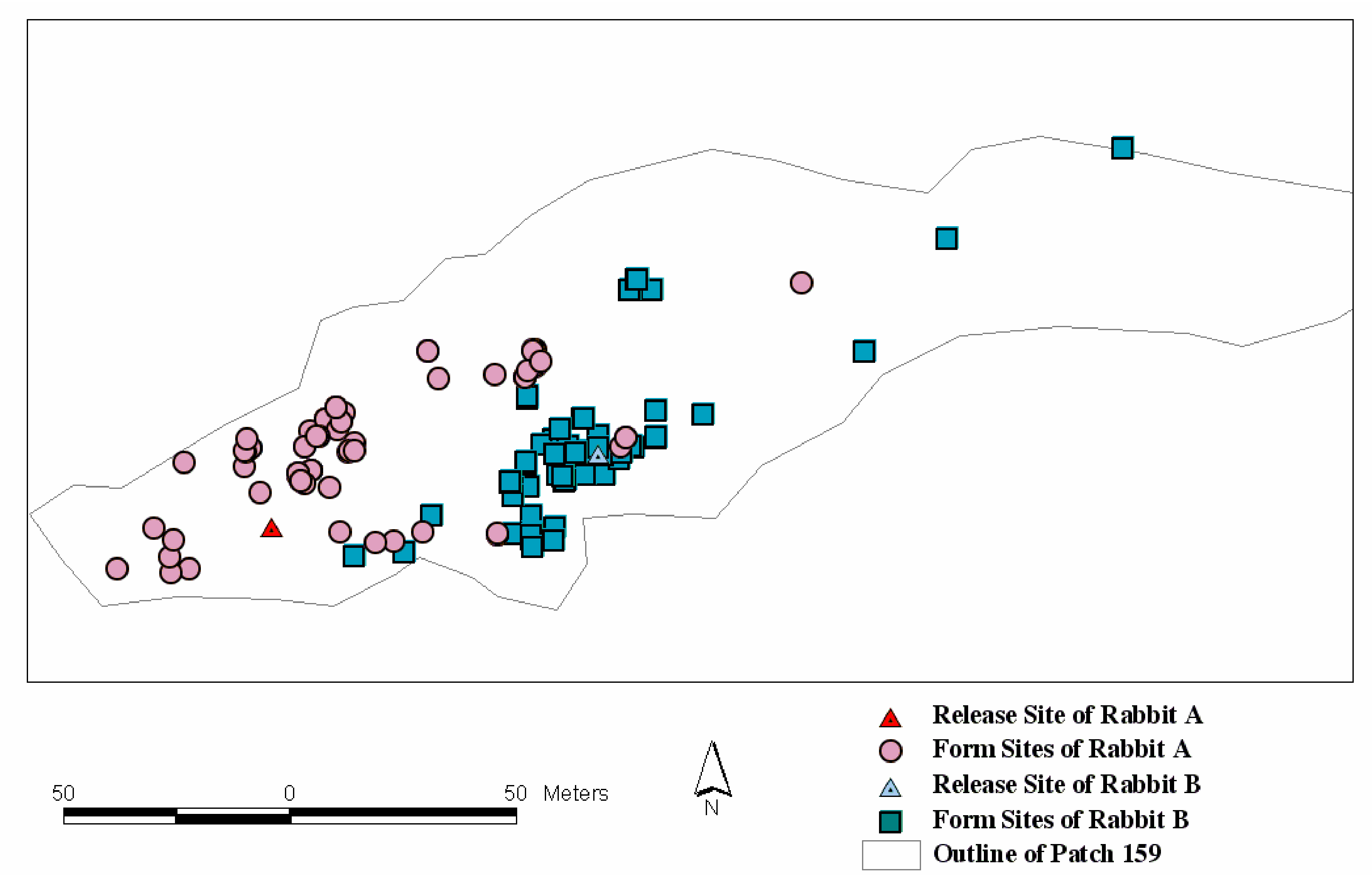

Fig. 3.7. Form sites of translocated male Lower Keys marsh rabbits in patch 159 on Little Pine Key in 2002. Form locations were located using radio telemetry. The point of release for each rabbit also is shown. The spatial distribution of form sites showed only occasional overlap.

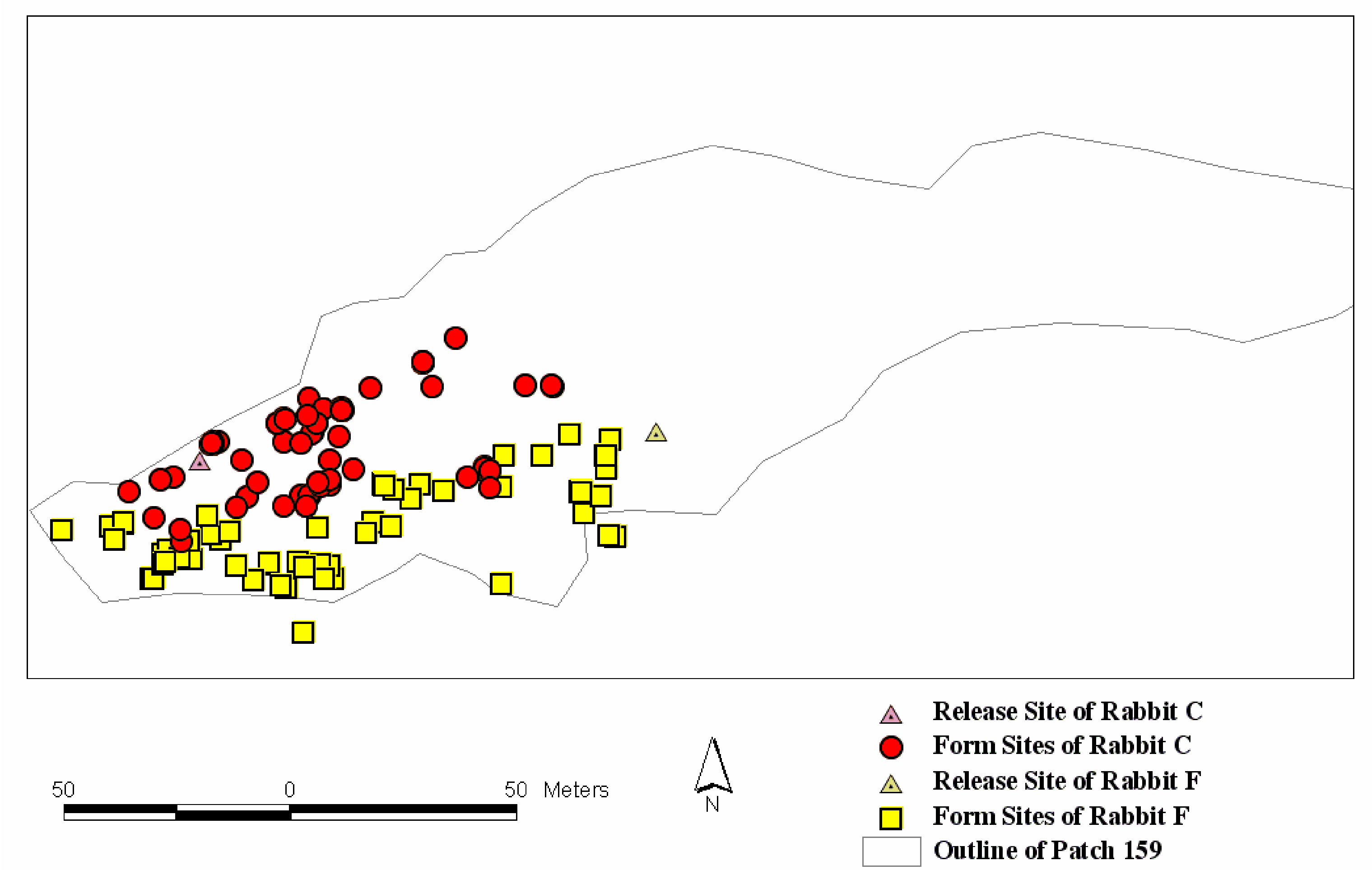

Fig. 3.8. Form sites of translocated female Lower Keys marsh rabbits in patch 159 on Little Pine Key in 2002. Form were located using radio telemetry. The point of release for each rabbit also is shown. The spatial distribution of form sites showed only occasional overlap. Rabbit C was found dead on 23 August 2002.

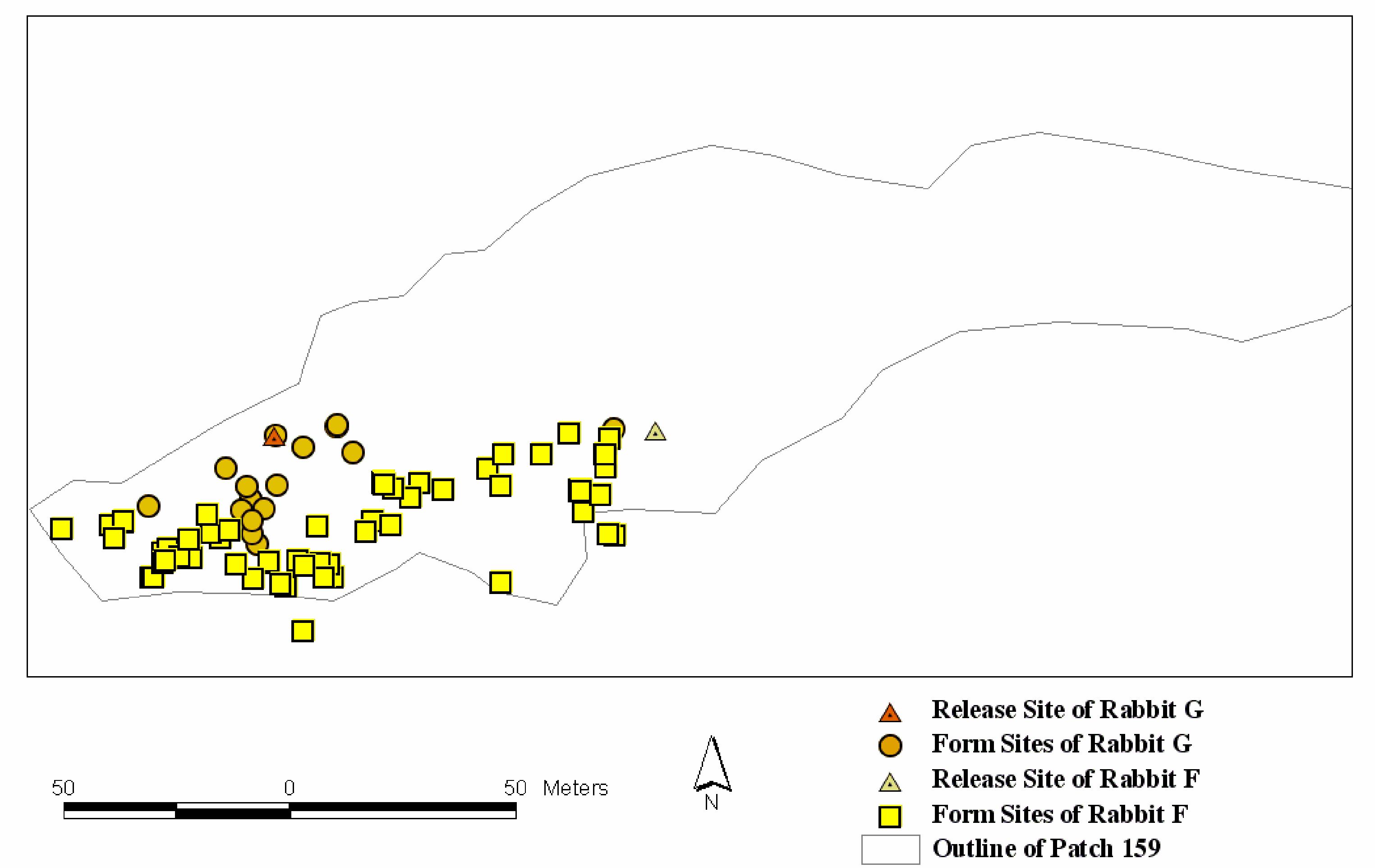

Fig. 3.9. Form sites of translocated Lower Keys marsh rabbits G and F in patch 159 on Little Pine Key in January 2002–March 2003. Forms were located using radio telemetry. The point of release for each rabbit also is shown. Rabbit G was translocated to the area on 24 October 2002 and occupied the area vacated by Rabbit C, which died on 23 August 2002. As had been the case with Rabbits C and F, the spatial distribution of form sites showed only occasional overlap.

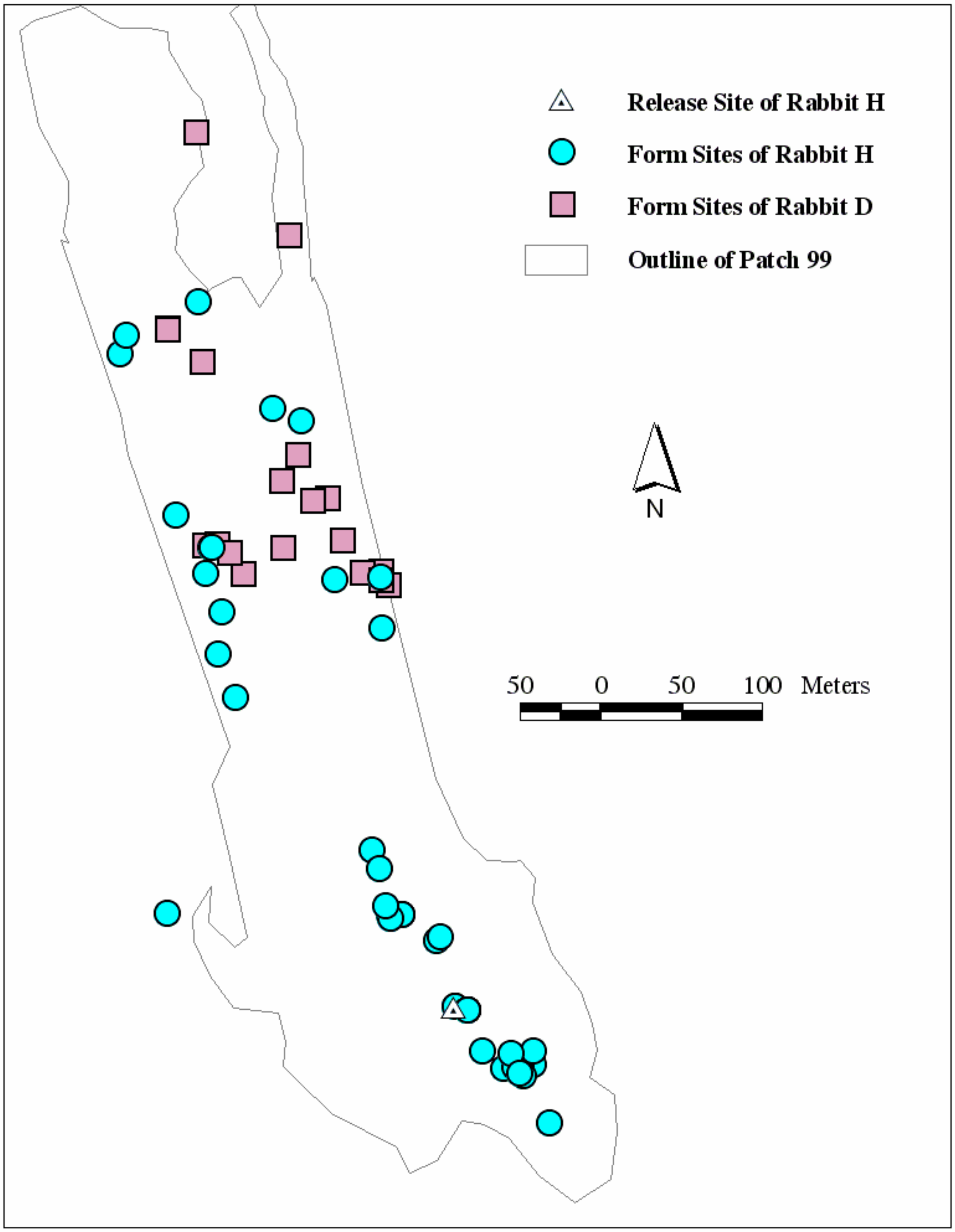

Fig. 3.10. Form sites of translocated male Lower Keys marsh rabbits in patch 99 on Little Pine Key in 2002. Forms were located using radio telemetry. The point of release for Rabbit H is shown. Rabbit D dispersed from patch 159 to patch 99. The spatial distribution of form sites showed some overlap, though Rabbit D tended to occupy the northern portion of the patch, and Rabbit H tended to occupy the s outhern portion.

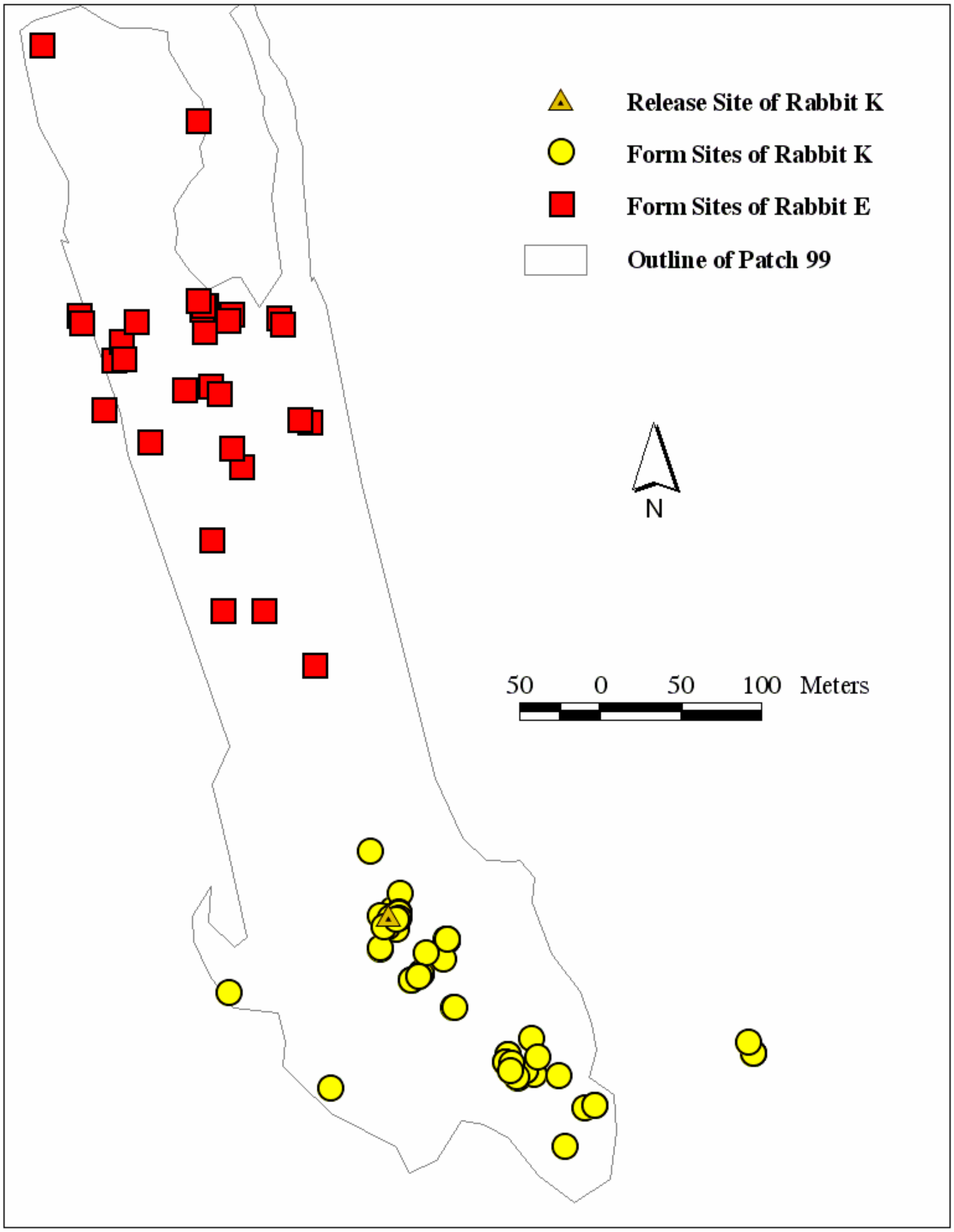

Fig. 3.11. Form sites of translocated female Lower Keys marsh rabbits in patch 99 on Little Pine Key in 2002. Forms were located using radio telemetry. The point of release for Rabbit K is shown. The spatial distribution of form sites showed no overlap. Rabbit E dispersed from patch 159 to patch 99.

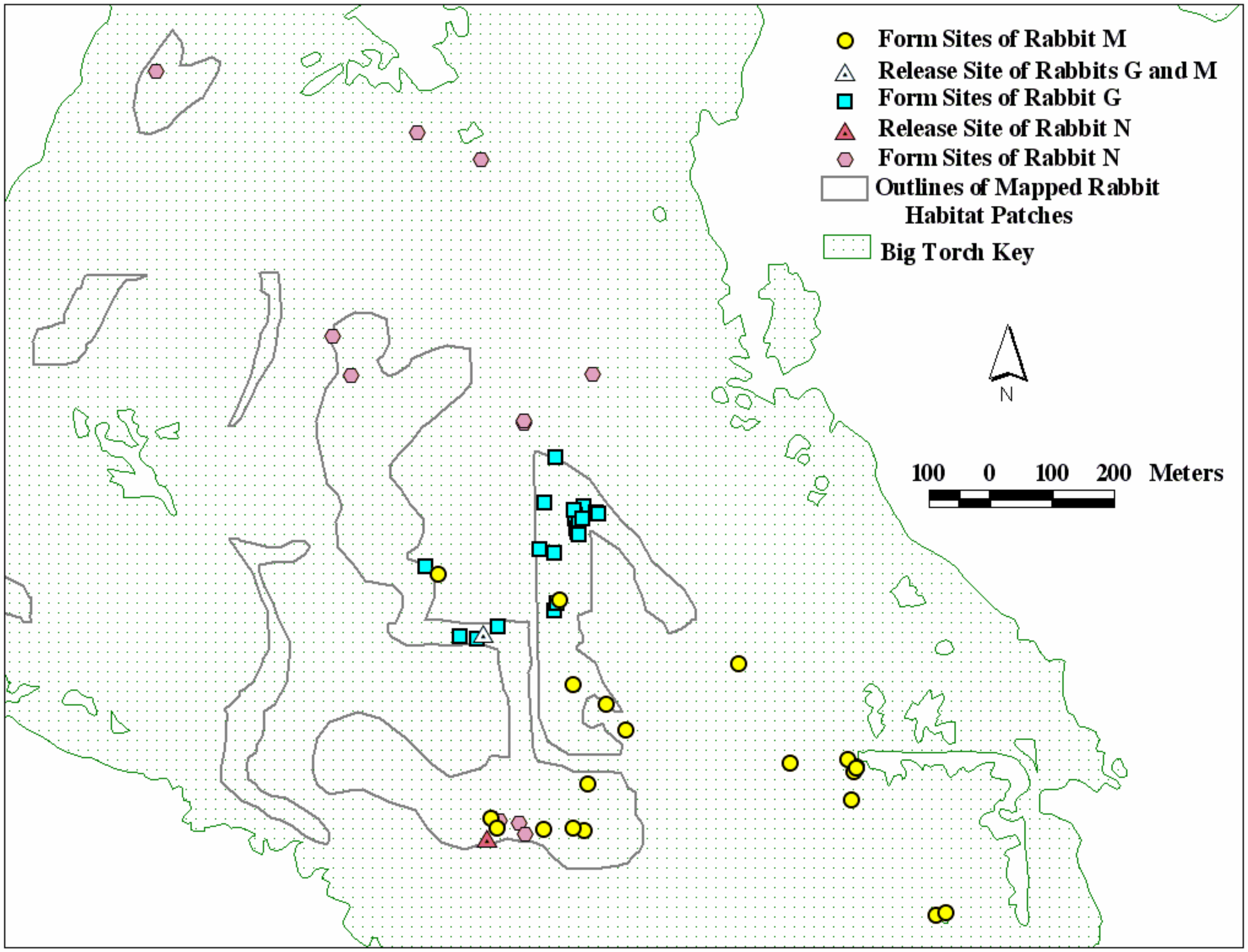

Fig. 3.12. Form sites of translocated rabbits on Big Torch Key in 2002. Forms were located using radio telemetry. The point of release for each rabbit also is shown. Rabbits M and N made movements outside of the mapped habitat patches.

In the beginning of October 2002, the USFWS decided to discontinue the Big Torch Key reintroduction until a later date. The USFWS was concerned about potential issues that might develop if reintroduced LKMRs spread to adjacent, undeveloped-privately-owned parcels of land. Attempts were made to recapture the Big Torch Key rabbits to bolster the Little Pine Key reintroduction. However, only the 1 female was recaptured.

In summary, the adult female survived 4 months on Big Torch Key, followed by at least 5 months on Little Pine Key. One adult male survived for at least 1.5 months, but his fate was unknown. The other adult male survived at least 6 months on Big Torch Key and may still be alive.

None of the rabbits appeared to establish ranges in close proximity to their point of release (Fig. 3.12). Mean distances from the point of release for Rabbits G, M, and N were 187 m (SD 89), 432 m (SD 237), and 912 m (SD 249), respectively. All locations were used in the calculations. Locations for these animals were relatively few due to problems with radio collars. Rabbits G, M, and N were located 23, 20, and 12 times, respectively. The female established a fairly stable range within 6 days of being translocated (Fig. 3.12). This rabbit was translocated from a freshwater wetland and was released in a freshwater hardwood area, but she chose to establish her range in an area of freshwater hardwoods and saltmarsh/buttonwood transition zone. The second male was found within 65 m of his release site for at least 4 days before moving >600 m north. The locations of all 3 rabbits often fell within or just outside of patches 49 and 79 (Fig. 3.12). The 2 males made sojourns outside of potential population 49, but > 50% of their locations fell within or just outside of patches 49 and 79. On these sojourns, the rabbits' form sites were all within saltmarsh/buttonwood transition zone, freshwater wetland, and mangrove vegetation types.

No juvenile pellets were found in the release area on Big Torch Key, and the males and female were rarely found in close proximity (Fig. 3.12). The distribution of the females' form sites showed little overlap with that of Rabbit M, though the 2 rabbits were found <10-m apart on 26 July 2002. The female's observed form sites never overlapped with those of the Rabbit N (Fig. 3.12).

Control-group Monitoring.-- Eleven of 14 control group rabbits (79%) survived >5 months (Table 3.4). Two additional rabbits died after surviving > 5 months. Cause of mortality could not be determined for 3 of the 5 observed mortalities. One adult male on Big Pine Key was killed by an eastern diamondback rattlesnake, and an adult male on Boca Chica Key was dragged by a predator into a crawl-space under a building. A cat was captured near the entrance to the crawl-space 2 days later.

DISCUSSION

Acquisition of Individuals and Translocation

Un-baited traps in tunnels and drift fence arrays appeared to be the best methods for trapping LKMRs. Blair (1936) and Forys (1995) also used un-baited traps to capture marsh rabbits. Drift fences with a height of 0.3-m rather than 0.46m seemed to be equally effective and were easier to work with in the field. Unfortunately, capture probabilities were low, underscoring the need for an effective bait. Baits, however, were ignored by rabbits or attracted unwanted animals such as raccoons. N. Perry (Texas A&M University, personal communication) recently attempted to use rolled oats and molasses to trap LKMRs, but only black rats were captured. Development of an effective rabbit attractant would benefit future studies of this species.

Once measures were taken to eliminate raccoon predation, procedures for trapping and handling rabbits worked well. Most LKMRs were relatively calm and easy to handle. The only rabbit to die during handling was particularly aggressive and agitated. In the future, aggressive rabbits could be restrained using the small cat sacks used by veterinarians. If rabbits do not become calm after being restrained for several minutes, it is recommended that they be released immediately to prevent injury or mortality. The methods for transporting rabbits proved to be safe and effective, as there appeared to be no injuries or mortalities resulting from the translocation.

Although trapping occurred in only a fraction of the area encompassed by each population, trapping was usually conducted in the sites with the highest pellet densities. Nonetheless, the abundance estimates were still conservative due to the negative bias of the MNKA and the low trapping probability for the subspecies. In some areas, no rabbits were captured despite the fact that LKMRs were flushed near traps and/or fresh fecal pellets were present. Procedures for acquiring individuals did not appear to injure source populations, as the habitat patches used for trapping remained occupied 1 year after the translocations. There were, however, fewer potential source populations than anticipated, as most LKMR populations appear to be small in size. This might limit the number of future reintroductions that can be conducted concurrently, especially if follow-up translocations are necessary (see below). Translocations with a larger number of individuals tend to be more successful (Griffith et al. 1989, Fischer and Lindenmayer 2000), but translocations can contribute to the decline and eventual extirpation of source populations (Todd et al. 2002). Consequently, managers must strike a balance between facilitating successful reintroductions and protecting the health of source populations.

This balance could be achieved by the development of an *in-situ* captive breeding program. This would involve fencing in a piece of suitable habitat, removing predators, and introducing adult LKMRs. Because LKMRs live in relatively-small habitat patches (Chapter II), these efforts would require little space (perhaps 0.5–1 ha) and few individuals (perhaps 1 adult male and 1–2 adult females). Breeders would be rotated out to promote genetic diversity, with former breeders being used for current reintroductions or to augment past reintroductions. This approach overcomes some of the disadvantages of *ex-situ* captive breeding, including behavioral, genetic, and physiological adaptation to a captive environment; failure to breed in an unfamiliar environment; and exposure to unfamiliar diseases (Allendorf 1986, Lacy 1994, Snyder et al. 1996, Williams et al. 2002). Recently, *in-situ* captive breeding has been employed successfully in reintroduction programs for the riparian brush rabbit in California (Williams 2002; L.P. Hamilton, Endangered Species Recovery Program, personal communication) and burrowing bettong in Australia (Short and Turner 2000). An *in-situ* captive breeding program, even on a limited scale, would allow reintroduction to be more widely applied for the LKMR without fear of damaging source populations.

Post-release Monitoring

The Little Pine Key reintroduction met all 3 criteria for short-term success, but the loss of radio collar signals made post-release monitoring more difficult for the Big Torch Key reintroduction. Big Torch Key is narrow (<2 km at the widest point) and is bisected by a road. Thus, given the range of the transmitters, a signal should have been relatively easy to obtain. Plus, a boat used around the perimeter of the island and some of the neighboring outer islands failed to locate radio signals. Therefore, collar failure was the most likely explanation for the disappearance of 1 male and the intermittent signal of the other male.

Little Pine Key rabbits had a high survival rate during the establishment phase. Survival of known-fate translocated rabbits was similar to that of control rabbits tracked during the same time period. Plus, at least 2 of the 3 rabbits on Big Torch Key survived through the establishment phase. Comparable survival has been reported for translocated riparian brush rabbits (*Sylvilagus bachmani riparius*) in California (L.P. Hamilton, Endangered Species Recovery Program, personal communication). High initial mortality has been demonstrated for translocated European rabbits in Spain and France (Calvete et al. 1997, Letty et al. 2000), and translocated LKMRs exhibited higher survival than translocated snowshoe hares (*Lepus americanus*) in Ohio (Swanson 2002). Relatively-high survival of the released animals is critical for the success of a LKMR reintroduction program because small population sizes prohibit the translocation of large numbers of individuals. Considering the high mortality following release for reintroductions of a variety of taxa (see Sarrazin and Legendre 2000 for a review), the survival of translocated LKMRs was encouraging.

Most translocated LKMRs exhibited site fidelity following release. Exceptions might be explained by the social behavior of the species. The departure of a subadult female from the western release site on Little Pine Key was preceded 2 weeks earlier by the addition of an adult female. The larger adult female may have forced the subadult female out, possibly due to overcrowding in the best habitat. The ranges of same-sex LKMRs rarely overlap (Forys 1995). Female *Sylvilagus floridanus* are known to develop a social hierarchy, though *S. aquaticus* females only display occasional dominant-subordinate interactions (Marsden and Holler 1964),

On Big Torch Key, the wandering of males may be explained by attempts to find possible mates. The first male was present for 2 weeks prior to the release of the female, and telemetry data suggested he may not have located her for some time after her release. Likewise, the second male may not have located the female initially due to the large size of the release area. Alternatively, the presence of the first male may have forced the second male to look elsewhere to find a mate. This hypothesis for male movements on

Big Torch Key might also explain why a male on Little Pine Key, whose range did not originally overlap with that of a female, appeared to follow a subadult female to the southern release area.

Rabbits were translocated to Little Pine Key during the peak period of breeding for the mainland subspecies (Holler and Conaway 1979), but there appeared to be a delay of as many as 6 months before translocated LKMRs reproduced. A similar delay seemed to operate on Big Torch Key, where juvenile pellets were never found. A delay in the onset of reproduction may have resulted from stress associated with a novel environment. It is possible, however, that reproduction occurred sooner but was not detected, as juvenile pellets proved difficult to find in areas with thick grass. Moreover, previous breeding attempts may have ended in nest failure due to predation by raccoons or possibly by black rats. During a range-wide distribution survey for the species, juvenile pellets were encountered infrequently (Chapter II).

Ideally, short-term monitoring should quantify reproduction of translocated individuals (Scott and Carpenter 1987, Nielsen 1988). Williams et al. (2002) planned to quantify reproductive success of translocated riparian brush rabbits through periodic capture and marking of new individuals. Quantifying reproduction is a difficult task for the LKMR because nests can be difficult to find, early depredation of nests may not be detected, and trapping success is low. Juvenile pellet surveys, though not ideal, may provide the best (i.e., least potential harm to animals and habitat, least time and labor) way to detect reproduction for this species.

MANAGEMENT IMPLICATIONS

Managers must be aware that the goal of a self-sustaining population is difficult to achieve, and reintroduced populations may need to be closely monitored and managed (Short et al. 1992, Seddon 1999). The Little Pine Key reintroduction and future efforts will require implementation of a long-term monitoring scheme and a genetic management plan.

Long-term Monitoring

Long-term monitoring is essential for determining the success of reintroduction efforts (Dodd and Seigel 1991, Seddon 1999). Given the LKMR’s cryptic nature and low probability of capture, long-term monitoring will use fecal pellets as an index of rabbit density. To ensure monitoring will continue over many years, monitoring protocols must be easy to use and insensitive to differences among observers, and the protocols must not be overly time-consuming or costly. Furthermore, the index must be calibrated to ensure it accurately reflects trends in LKMR density. Researchers are currently developing an index and monitoring protocols that meet these requirements (N. Perry, Texas A&M University, personal communication).

Genetic Management Plan

Although demographic and environmental stochasticity pose the most immediate threats to LKMRs on Little Pine Key, genetic considerations also must be addressed. Founder effects, genetic drift, and inbreeding could reduce the genetic diversity within the Little Pine Key populations (Lande 1988, Hedrick and Kalinowski 2000). In small, isolated populations, loss of heterozygosity can lead to inbreeding depression through an increase in frequency or the fixation of detrimental alleles, and a loss of alleles per locus could reduce the ability of the populations to adapt to environmental changes (Allendorf 1986, Hedrick and Kalinowski 2000).

One solution to this problem is to artificially facilitate gene flow via follow-up translocations (Ramey et al. 2000). The addition of new individuals could have both genetic and demographic benefits that could increase the persistence time of translocated populations (i.e., the "rescue effect," Brown and Kodric-Brown 1977). *In-situ* captive breeding could provide the individuals necessary for these follow-up translocations (Short and Turner 2000).

It has been suggested that 1 migrant per generation time is the minimum necessary to maintain genetic diversity (Mills and Allendorf 1996). Adding >1 migrant-per-generation time would be ideal both from a genetic standpoint and to ensure at least 1 of the migrants reproduces (Mills and Allendorf 1996, Couvet 2002). However, managers also must consider the effects of additional migrants on habitat quality (Ramey et al. 2000). Moreover, follow-up translocations carry some risks, as individuals may fail to integrate into and breed within established populations (Van Zant and Wooten 2003). Migrants could be forced into marginal habitat by established LKMRs, which exhibit spacing behavior and little same-sex range overlap (Forys 1995). If too many migrants are added to the translocated population, individuals that could have reproduced in source populations or as part of another reintroduction may fail to breed. Therefore, follow-up translocations to Little Pine Key should be limited to 1 rabbit per generation time, and follow-up translocations should be monitored via radio telemetry to judge their effectiveness (e.g., Van Zant and Wooten 2003).

A "generation time" can be defined as the time between reproduction of the parent generation and reproduction of their offspring (Lincoln et al. 1998:123). In a population of marsh rabbits (*S. p. paludicola*) in southern Florida, 22% of juvenile females 6–9 months of age were pregnant, and a significant portion of juvenile males could be considered fertile (Holler and Conaway 1979). Most female rabbits were reproductively active at ≥9 months of age (Holler and Conaway 1979). Thus, a LKMR generation time could be defined as anywhere between 6–10 months (depending on whether the 30–37 day gestation period is included in the calculation).

Linklater (2003) suggested using the Trivers-Willard Model (Trivers and Willard 1973) of parental investment to determine the optimal sex to "invest in" (i.e., translocate) to promote gene flow. However, the LKMR does not fit all assumptions of the model. For instance, there was no evidence of lower male survival in this study, though sample size was small. I recommend alternating sexes in follow-up translocations to account for chance variation in the sex ratio due to demographic stochasticity.

The success of facilitating gene flow through follow-up translocations also may depend on the gene flow present in the source populations, as isolated source populations also may have deleterious alleles at higher frequencies or even fixed through genetic drift (Couvet 2002). Hence, it may be important to study the population genetics of potential source populations (Chapter IV). A future application of translocation might be to promote gene flow in source as well as translocated LKMR populations (Chapter IV).

Conclusions

Factors influencing the success of translocations can be divided into (1) those operating during the establishment phase and (2) those that affect the long-term persistence of the translocated population (Armstrong et al. 1999). In terms of the former, results suggest LKMRs can be transported without harm and established in a new environment. However, the movements of males on Big Torch Key and 1 adult male on Little Pine Key suggest that site fidelity might be improved by releasing males and females close together both in space and time or by releasing a female prior to releasing a male. This could be especially important in larger, less-discrete release areas such as on Big Torch Key. Short and Turner (2000) found improved site fidelity for burrowing bettongs (*Bettongia lesueur*) when males and females were released together compared to initial releases involving only males.

The site fidelity and high initial survival in my study suggest a soft release may not be necessary for the establishment of this species. Soft releases (e.g., releases providing acclimation pens, supplemental food, etc.) are thought to reduce mortality and increase site fidelity during establishment (Nielsen 1988, Bright and Morris 1994). However, most translocated LKMRs appeared to adapt readily to their new environment and their form sites were generally found in the intended patches. The ability to use a hard release reduces the staff time and monetary costs necessary for LKMR reintroductions.

The success of LKMRs during the establishment phase indicates that factors affecting the long-term persistence of the translocated population are the most important consideration for LKMR reintroductions. The key factor to consider is the quality of the release site. Release sites must provide adequate cover, forage, and nesting areas. This requires a sufficient knowledge of the habitat requirements of the species, and, ideally, how demographic parameters relate to habitat variables (Van Horne 1983, Garshelis 2000). The night movements of LKMRs and the extent of use of adjacent vegetation types are currently unknown and need to be elucidated. Additionally, managers should consider enhancing habitat quality at potential release sites by planting preferred cover species such as gulf cord grass. When evaluating potential release sites, managers must consider the landscape context as well as patch quality (Chapter IV). Factors such as the composition of the matrix between habitat patches, the proximity to development, and the number and size of neighboring habitat patches can affect the persistence of local populations (Wiens 1996, Hanski 1998, Mazerolle and Villard 1999).

Managers should seek to identify and remove the original cause of the extirpation in potential release sites (May 1991, Short and Turner 2000). This will be difficult, as formal population surveys did not occur until the rabbit’s population had already declined (Howe 1988), few historic and extant populations were identified in earlier surveys (Howe 1988, Chapter II), and some extirpations may have resulted from stochastic rather than deterministic events. Even if the historic cause of the extirpation cannot be determined, managers should strive to identify and remove current threats. The uncertainty in the cause of extirpations provides another reason to adopt an *in-situ* captive breeding approach, because a greater number of candidates for translocation would allow managers to treat reintroductions as an adaptive management experiment in which unforeseen threats are progressively identified and removed.

Because the Big Torch Key reintroduction was discontinued, this pilot program lacked the replication necessary for stronger inferences about the use of reintroduction for this species. Managers could employ metareplication to bolster the conclusions of this study (Johnson 2002). A reintroduction to Water Key was being planned at the time of this study (P. A. Frank, USFWS, personal communication).

Despite the lack of replication, the results of this study suggest reintroduction could be an effective conservation tool for the LKMR. However, reintroduction sites with quality habitat and isolation from human disturbance currently are limited in number (Chapter IV). Thus, reintroduction alone will not be enough to stem the decline of the LKMR metapopulation. Other potential reintroduction sites need to be restored or enhanced (Chapter IV). More importantly, the underlying causes for the subspecies' continued decline must be addressed. For example, a population viability analysis model based on data from the 1990s suggested increasing adult survival was the best way to promote the persistence of the subspecies (Forys and Humphrey 1999). Reintroduction must be integrated into a comprehensive management strategy involving land acquisition, control of exotic predators, and habitat restoration and enhancement.

CHAPTER IV

CONCLUSIONS ABOUT FUTURE MANAGEMENT AND RESEARCH

INTRODUCTION

The persistence of a metapopulation is governed by the dynamic interaction between local extinctions and colonization by dispersing individuals (Levins 1969, 1970; Hanski and Gilpin 1991). The rates of extinction and colonization are determined by processes operating at both the local and landscape scale. Patch habitat quality, for example, can be a significant factor governing metapopulation dynamics (Harrison 1991, Fleishman et al. 2002). Moreover, variation in the number of individuals in a local population affects both the length of a population's persistence and the number of dispersers sent out to other patches.

Landscape variables, in turn, have a significant effect on patch occupancy (Mazerolle and Villard 1999). The distance between patches and the size and number of neighboring patches influence the extinction rate and colonization rate (Hanski 1998). The composition of the matrix between habitat patches affects dispersal and hence the rate of colonization and can even isolate patches in close proximity to one another (Wiens 1996). Thus, as Levins (1970) noted, a species may disappear from an area even if optimal habitat is present.

Thus, managing metapopulations requires a local and a landscape perspective, as well as an understanding that processes operating at both scales are intimately linked. Management actions should be directed toward both the best suitable habitat patches and the intervening landscape, recognizing that unoccupied patches also should be monitored and protected (Wiens 1996, Hanski 1998).

These management principles for metapopulations apply to the case of the LKMR. Listed as a federally-endangered species in 1990, the LKMR exists as a metapopulation in patches of saltmarsh/buttonwood transition zone, freshwater wetlands, and coastal beach berm in Florida's Lower Keys (USFWS 1990, Forys and Humphrey 1996). The primary reason for the species' decline was the loss and fragmentation of its habitat from human development, much of which occurred from 1970–1996 (USFWS 1997, 1999). Secondary, or indirect, impacts from development posed further threats to the rabbit's persistence through direct mortality and degradation of habitat (USFWS 1999). For example, cats and vehicles caused over half of the mortalities observed by Forys (1995) on Boca Chica Key. Ensuring the persistence of the LKMR metapopulation necessitates management actions aimed at addressing the primary and secondary impacts of human development at both the local and landscape scales. These actions should include land acquisition, reintroduction to suitable habitat, identification and control of secondary impacts from current and proposed development, and habitat restoration and enhancement. It is suggested that future research address the population genetics of the LKMR.

LAND ACQUISITION

Currently, wetland regulations provide protection from development for much of the LKMR's habitat (e.g., Section 9.5-347 and 9.5-348 of the Monroe County Code). Nonetheless, ensuring prevention of future loss and fragmentation of LKMR habitat will require the acquisition of privately-owned land in remaining areas of occupied and potential LKMR habitat. Land acquisition will facilitate efforts to restore and enhance occupied and potential habitat, reintroduce LKMRs to suitable patches, and control secondary impacts from human development. Moreover, land acquisition also is necessary to preserve connectivity between populations, as successful dispersal between habitat patches is critical to the persistence of a metapopulation (Hanski and Gilpin 1991).

At the time of my study, the Monroe County Department of Planning and Environmental Resources (MCDPER) was developing a Tier system for land-use planning in order to implement the County's comprehensive plan (Monroe County Growth Management Division 1993) and to prioritize land acquisition. Land parcels were classified into 3 tiers (MCDPER, unpublishded data):

1. Tier 1, environmentally sensitive lands slated for acquisition
2. Tier 2, a "holding area" for parcels that might be reclassified into Tier 1 or Tier 3
3. Tier 3, parcels set aside for future development.

The objectives of this section were (1) to provide a method for prioritizing land acquisition efforts for the LKMR and (2) to assess whether the proposed Tier system of MCDPER provides adequate protection for LKMR habitat and connectivity between patches.

Prioritization of Land Acquisition

Efforts to acquire and protect lands important to the LKMR should be prioritized in the following manner:

1. Land acquisition efforts should focus first on the area encompassed by occupied local populations, as metapopulations with fewer local populations bear an increased risk of extinction (Hanski 1998). Moreover, acquisition of these areas will facilitate habitat restoration and enhancement efforts.
2. The second priority should be to purchase and protect the area encompassed by the most suitable potential populations. The number of local populations can be increased by artificial colonization (i.e., reintroduction) of suitable potential habitat. This would not only increase the size of the metapopulation, but would help to spread risk in case of an environmental catastrophe such as a disease or major hurricane.
3. The third priority should be the acquisition of potential dispersal areas to ensure connectivity between occupied and highly ranked potential populations. Given the small size of most habitat patches (Chapter II), dispersal between occupied and highly ranked potential populations is critical to the persistence of individual local populations and the metapopulation as a whole.

4. Finally, it would be wise to consider acquiring privately-owned land within lower-ranked potential populations. If current conditions change (e.g., if feral and domestic cat control is implemented, or if habitat is enhanced or restored), these areas may become suitable reintroduction sites in the future.

Land ownership patterns were explored in ArcView (Version 3.2) by overlaying data on LKMR habitat and dispersal areas (Chapter II) on land parcel data obtained from MCDPER. Patches that had been destroyed or rendered completely unsuitable for rabbits were excluded from the analyses (Chapter II). The parcel data were an updated and modified version of 1999 property-tax data from the Monroe County Property Appraiser's office and included the Tier designations by MCDPER. The ownership status (public or private) and Tier designation were determined for each parcel that intersected LKMR habitat and dispersal areas. The land parcel data did not always align perfectly with DOQQs. In these exceptions, an attempt was made to eliminate parcels that did not actually intersect LKMR habitat.

Occupied Local Populations.--Twenty-nine and 38% of occupied local populations occurred on land entirely under public (or public and The Nature Conservancy [TNC]) and military ownership, respectively. Eleven and 23% of occupied local populations occurred on privately-owned land or land under a combination of private and public ownership, respectively. Four hundred forty-two undeveloped, privately-owned parcels totaling 485 ha intersected occupied local populations (Fig. 4.1–4.5.). In addition, 7 parcels (54 ha) with <50% development intersected occupied local populations (Fig. 4.1–4.5).

Most Suitable Potential Populations.-- A Potential Habitat Score was developed to determine the most suitable potential populations. Potential populations were scored at 3 scales: patch scale, scale of the total area available to a potential population (TAPP), and landscape scale (Appendix D). At the patch scale, each patch received a score based on the following criteria: availability of potential form sites, herbaceous-ground cover, and susceptibility to flooding (Table 4.1). Radio tracking indicated LKMRs commonly use tall, thick grasses and sedges for form sites, though they also will take cover at the base of shrubs and trees (Appendix A). Categories for the herbaceous ground cover criterion were based on the estimated minimum amount of herbaceous-ground cover found in any occupied patch. Susceptibility to flooding was included as a criterion because it was assumed regular flooding would limit the number of form sites available to rabbits. For example, Layne (1974) observed marsh rabbits in mainland Florida congregating on areas of high ground during flooding.

The area-weighted mean patch score was determined for each potential population, and this measure comprised 80% of the score at the TAPP scale. The total area of all patches in each potential population accounted for the other 20% of the score (Table 4.2).

The following criteria were used to construct a landscape-scale score for potential rabbit populations (percent of total score in parentheses; Table 4.3):

1. The proximity index (20%), which considers both the distance to neighboring populations and the number and size of neighboring populations (Gustafson and Parker 1992, McGarigal and Marks 1995),
2. Dispersal connectivity (20%), which examines whether potential impediments to dispersal (i.e., human development, large bodies of water) isolate a potential population from other OPLPs,
3. Distance to human development (30%), which focuses mainly on the threat of cats,
4. And distance to paved roads (30%), which takes into account the threat of vehicle mortality.

All landscape-scale analyses were completed using ArcView (Version 3.2) with the Spatial Analyst extension.

The proximity index was calculated using the following formula:

$$\sum_{s=1}^{n} (a_{ijs}/h_{ijs}^{2})$$

where a_{ijs} equals the area (m^2) of potential population ijs within a given radius of the focal potential population ij, and h_{ijs} equals the edge-to-edge distance between the focal potential population ij and neighboring population ijs within a specified radius (McGarigal and Marks 1995). When calculating a_{ij}, roads and scarified areas were removed. The h_{ijs} were calculated by creating a cost-distance grid using the Cost Distance Tools ArcView extension. This method of calculating h_{ijs} was chosen because it took into account areas that dispersing LKMRs would be unlikely to cross (e.g., large bodies of water), thereby measuring distance "as the rabbit travels" rather than "as the crow flies." Proximity-index rankings were based on the distribution of proximity-index values for occupied local populations(Table 4.3). A radius of 3,000 m was selected for the analyses. This value seemed reasonable given the dispersal behavior of members of the genus. For example, a subadult female LKMR was radio-tracked until it was killed 660 m from its place of capture, and 2 reintroduced LKMRs on Little Pine Key moved 1,900 m and 2,200 m, respectively, from their release site (Chapter III). Forys (1995) observed male LKMRs dispersing as far as 2,050 m on Boca Chica Key. Schwartz (1941) determined that 5 dispersing eastern cottontails (*Sylvilagus floridanus*) moved < 1,600 m, but Dalke and Sime (1938) captured 4 eastern cottontail dispersers 1,600-3,800 m from their natal site. In a model for a New England cottontail (*S. transitionalis*) metapopulation, Litvaitis and Villafuerte (1996) considered 3,000 m to be a reasonable estimate of the species' maximum dispersal distance.

Table 4.1. Patch-scale criteria for the Potential Habitat Score developed to evaluate Lower Keys marsh rabbit potential populations. The overall score for the patch scale was equal to the sum of the weighted scores for the 3 criteria.

Potential form sites (cover)	**Score**	**Weighted score**
Form sites infrequent or not present	0	0
Form sites present, but not abundant	1	15
Form sites abundant, but few bunch grasses	2	30
Form sites abundant, 0.5 m tall bunch grasses >20%	3	45
Herbaceous groundcover (food)		
Herbaceous groundcover <25%	0	0
Herbaceous groundcover >25%	1	45
Susceptibility to flooding		
Almost all of the patch is flooded for much of the wet season	0	0
Most of the patch is flooded only occasionally during the wet season or receives no flooding	1	10

Table 4.2. Each potential Lower Keys marsh rabbit population was given a score based on the sum of the area of all of its constituent patches. The scores were weighted so this criterion comprised 20% of the total-area-available-to-a-potential-population-scale score for a Potential-Habitat-Scoring system.

Area of the patch	**Score**	**Weighted score**
<0.35 ha, the smallest LKMR range observed in this study	0	0
0.35–1ha	1	6.7
1–5 ha, approximately the inter-quartile range for all occupied and potential populations	2	13.3
>5 ha	3	20.0

Table 4.3. Landscape-scale criteria for the Potential Habitat Score developed to evaluate Lower Keys marsh rabbit potential populations. The overall score for the landscape scale was equal to the sum of the weighted scores for the 4 criteria. Percentiles refer to the distribution of proximity index values for occupied populations.

Proximity index (value in brackets)	Score	Weighted score
< 5th percentile (0.06) of occupied populations	0	0
≥ 5th percentile (0.06) and < 25th percentile (2.8)	1	6.7
≥ 25th percentile (2.8) and ≤ 75th percentile (51.8)	2	13.3
> 75th percentile (51.8)	3	20.0
Dispersal connectivity		
Dispersal to neighboring populations is impeded or blocked by human development or large bodies of water	0	0
Dispersal corridors provide access to neighboring populations	1	20.0
Distance to development		
Minimum distance < 320 m, and >50% of the land area within 320 m	0	0
Minimum distance < 320 m, but ≤50% of the land area within 320 m *or* 320 m < minimum distance < 940 m	1	10.0
Minimum > 940 m	2	20.0
Island with no development	3	30.0
Distance to roads		
Minimum < 30 m, and >50% of the land area within 30 m	0	0
Minimum < 30 m, but ≤50% of the land area within 30 m	1	15.0
Minimum > 30 m	2	30.0

Table 4.4. Potential Lower Keys marsh rabbit populations determined to be most suitable for rabbits by a Potential-Habitat-Score system in 2001–2003. Each potential population was made up of ≥1 patches of habitat. These patches were buffered by 60 m to account for uncertainty in habitat use and movements.

Population identification number	Sum of patch area (ha)	Total area (ha), including buffers	Key	Ownership
4	1.7	4.8	Boca Chica	Military
36	10.6	24.4	Sugarloaf	Private
64	3.0	15.1	Saddlebunch	Public
84	7.5	16.0	Big Torch	Mixed
92	1.3	4.6	S. Johnson	Public
94	2.5	10.0	S. Johnson	Public
99	10.5	24.8	Little Pine	Public
129	1.9	9.3	Water	Public
142	0.4	3.1	Little Pine	Public
150	1.7	10.1	Water	Public
159	1.5	6.8	Little Pine	Public
181	4.2	13.5	Little Torch	Mixed
188	0.5	14.9	Big Torch	Public
199	0.6	4.7	Saddlebunch	Public
201	1.2	5.0	Saddlebunch	Public
214	2.5	15.4	Cudjoe	Public
222	1.3	6.3	Cudjoe	Public

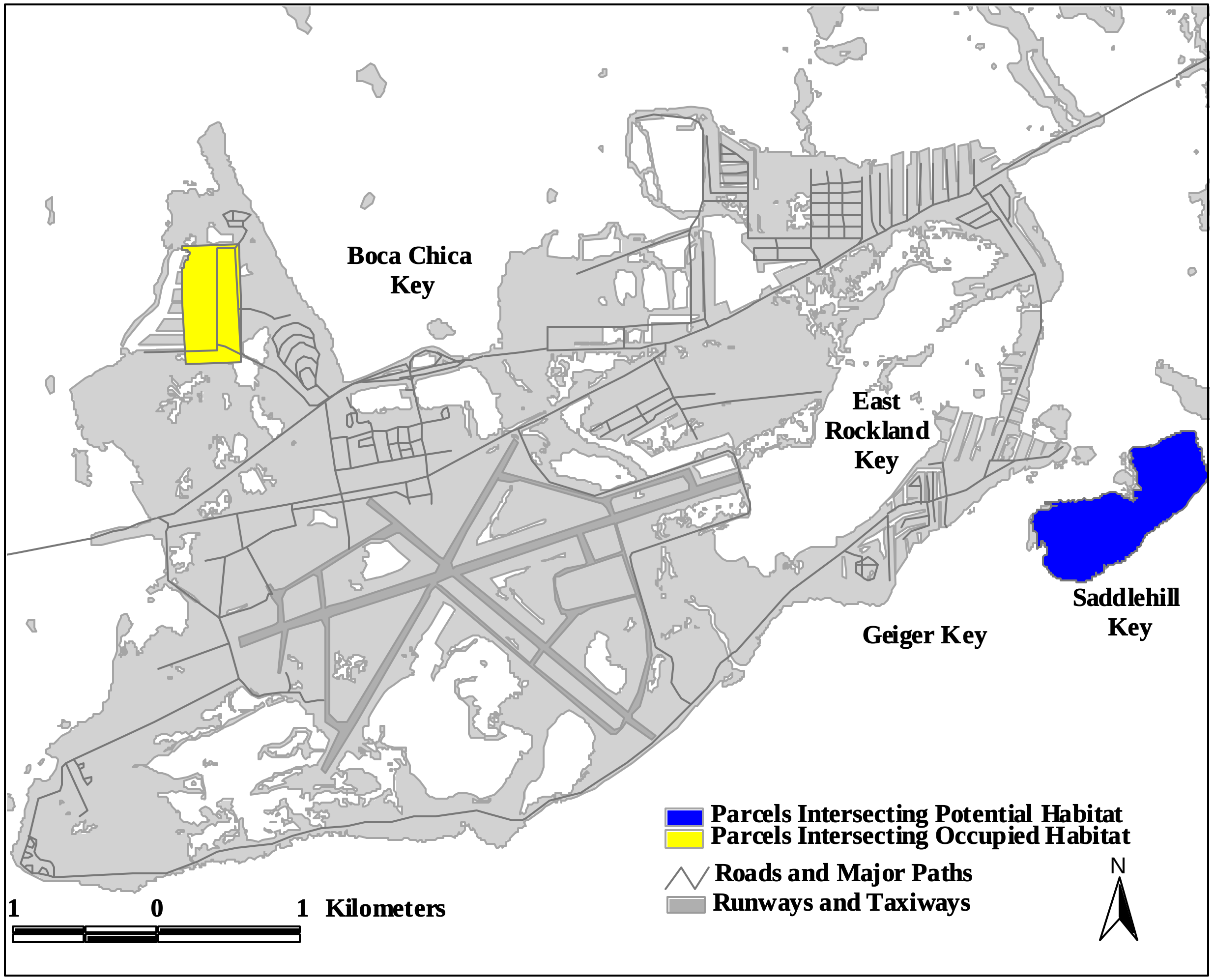

Fig.4.1. Undeveloped, privately-owned parcels of land intersecting the area encompassed by occupied or potential Lower Keys marsh rabbit populations on Boca Chica and Saddlehill keys in 2001–2003.

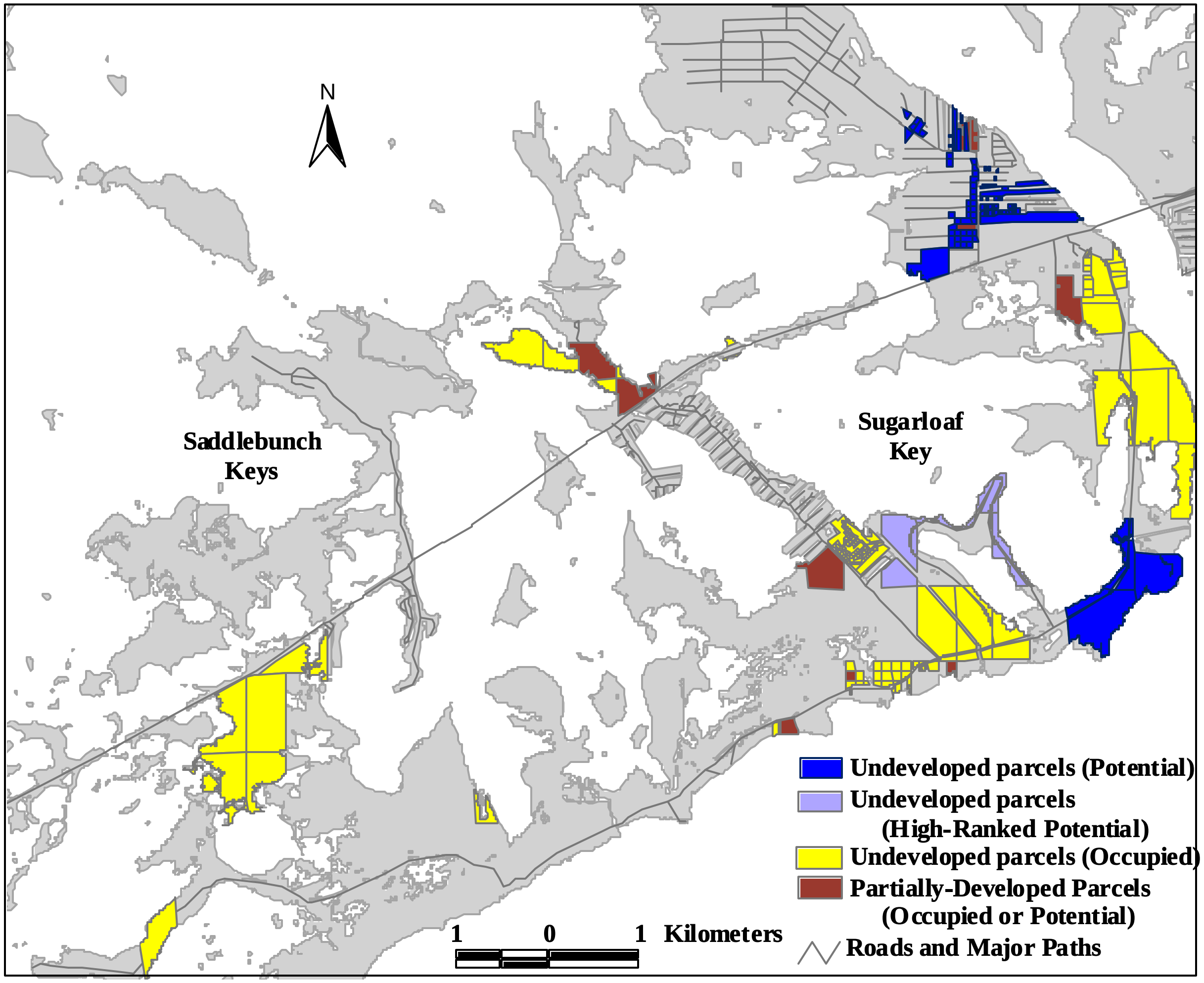

Fig. 4.2. Undeveloped and partially-developed (<50% developed) privately-owned parcels of land intersecting the area encompassed by occupied or potential Lower Keys marsh rabbit populations on Sugarloaf and the Saddlebunch keys in 2001–2003. Potential habitat that received a high Potential Habitat Score are distinguished from other areas of potential habitat.

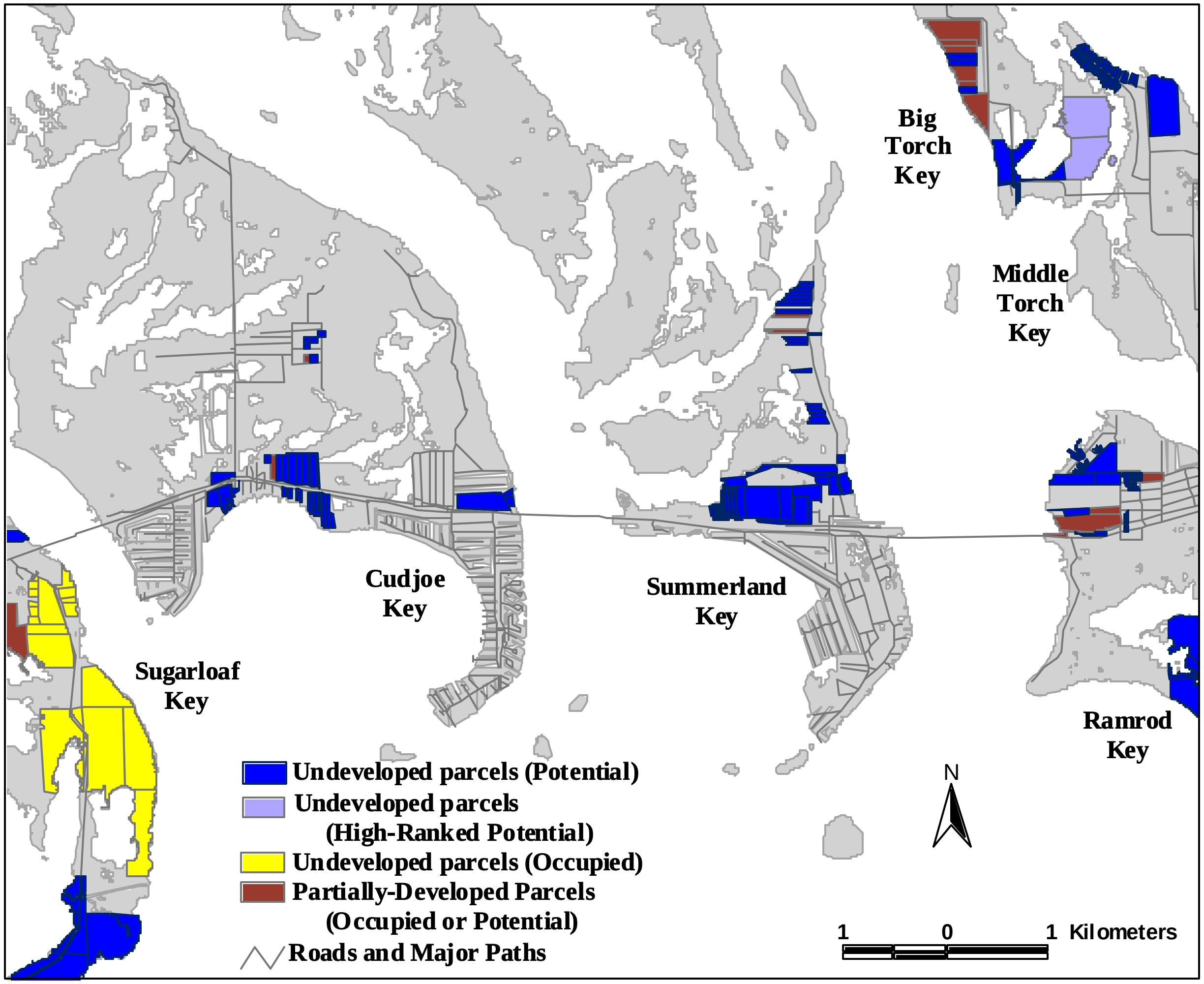

Fig. 4.3. Undeveloped and partially-developed (<50% developed) privately-owned parcels of land intersecting the area encompassed by occupied or potential Lower Keys marsh rabbit populations on Cudjoe and Summerland keys and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys in 2001–2003. Potential habitat that received a high Potential Habitat Score are distinguished from other areas of potential habitat.

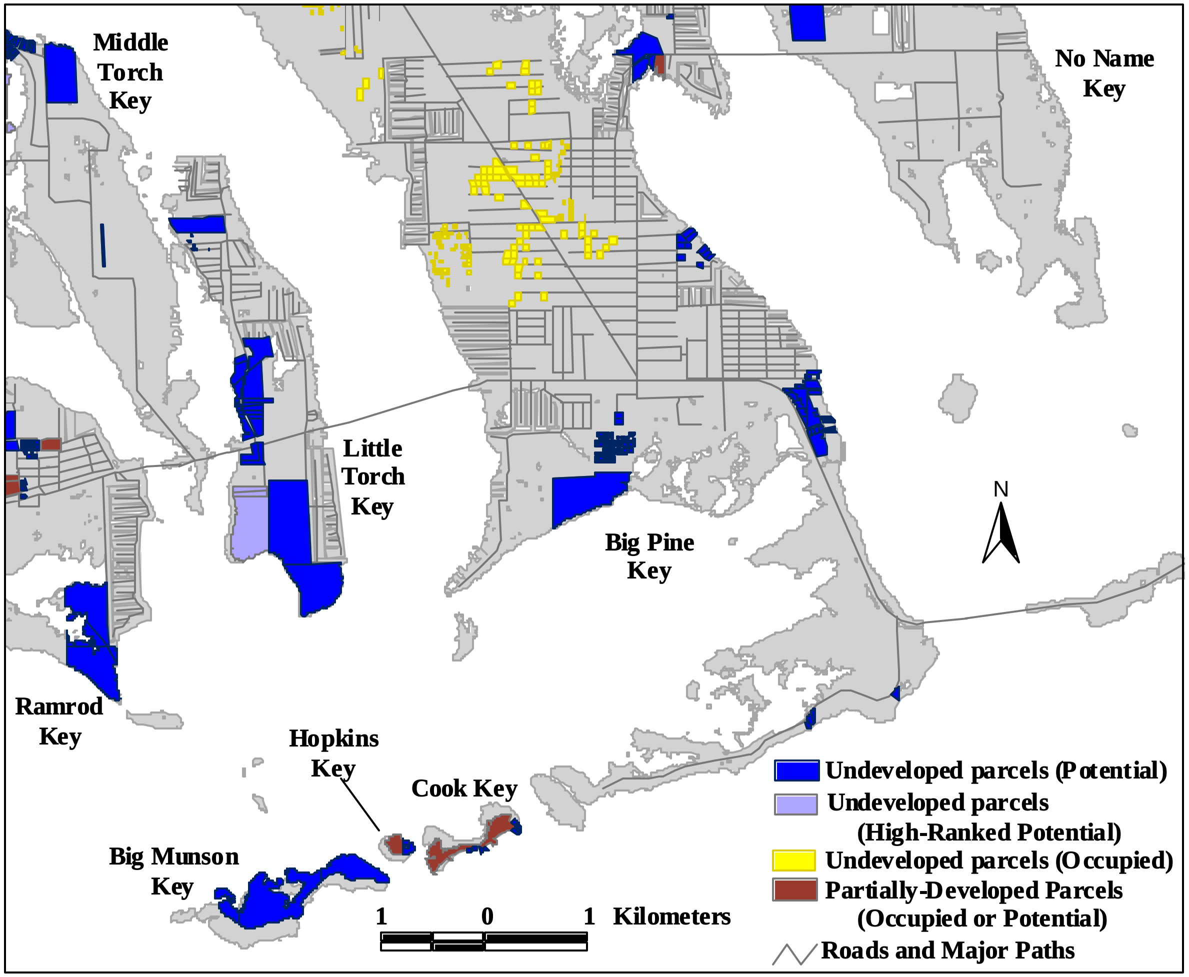

Fig. 4.4. Undeveloped and partially-developed (<50% developed) privately-owned parcels of land intersecting the area encompassed by occupied or potential Lower Keys marsh rabbit populations on Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Big Pine and Middle Torch keys from 2001–2003. Potential habitat that received a high Potential Habitat Score are distinguished from other areas of potential habitat.

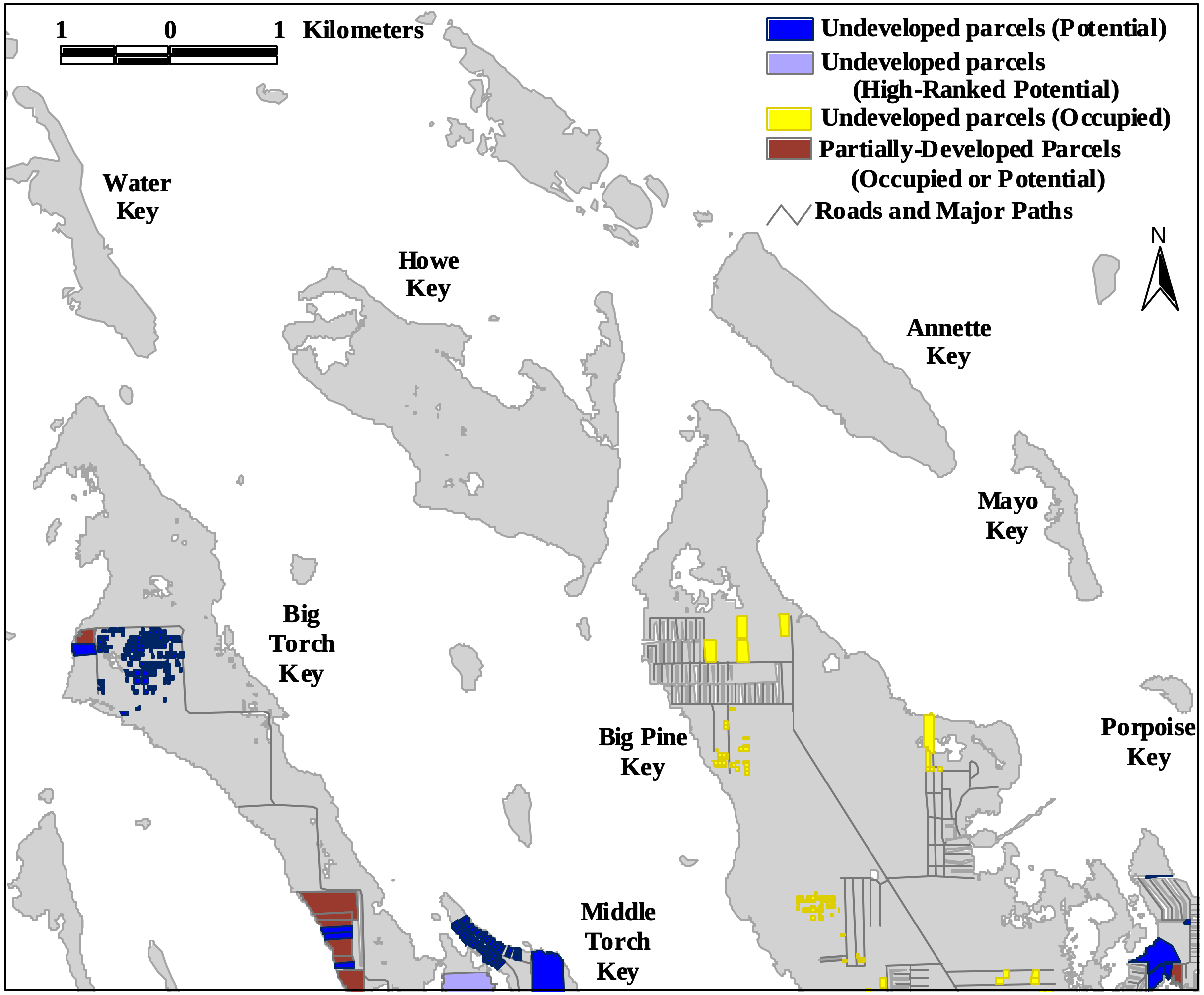

Fig. 4.5. Undeveloped and partially-developed (<50% developed) privately-owned parcels of land intersecting the area encompassed by occupied or potential Lower Keys marsh rabbit populations on Big Torch Key and portions of Middle Torch and Big Pine keys from 2001–2003. Potential habitat that received a high Potential Habitat Score are distinguished from other areas of potential habitat.

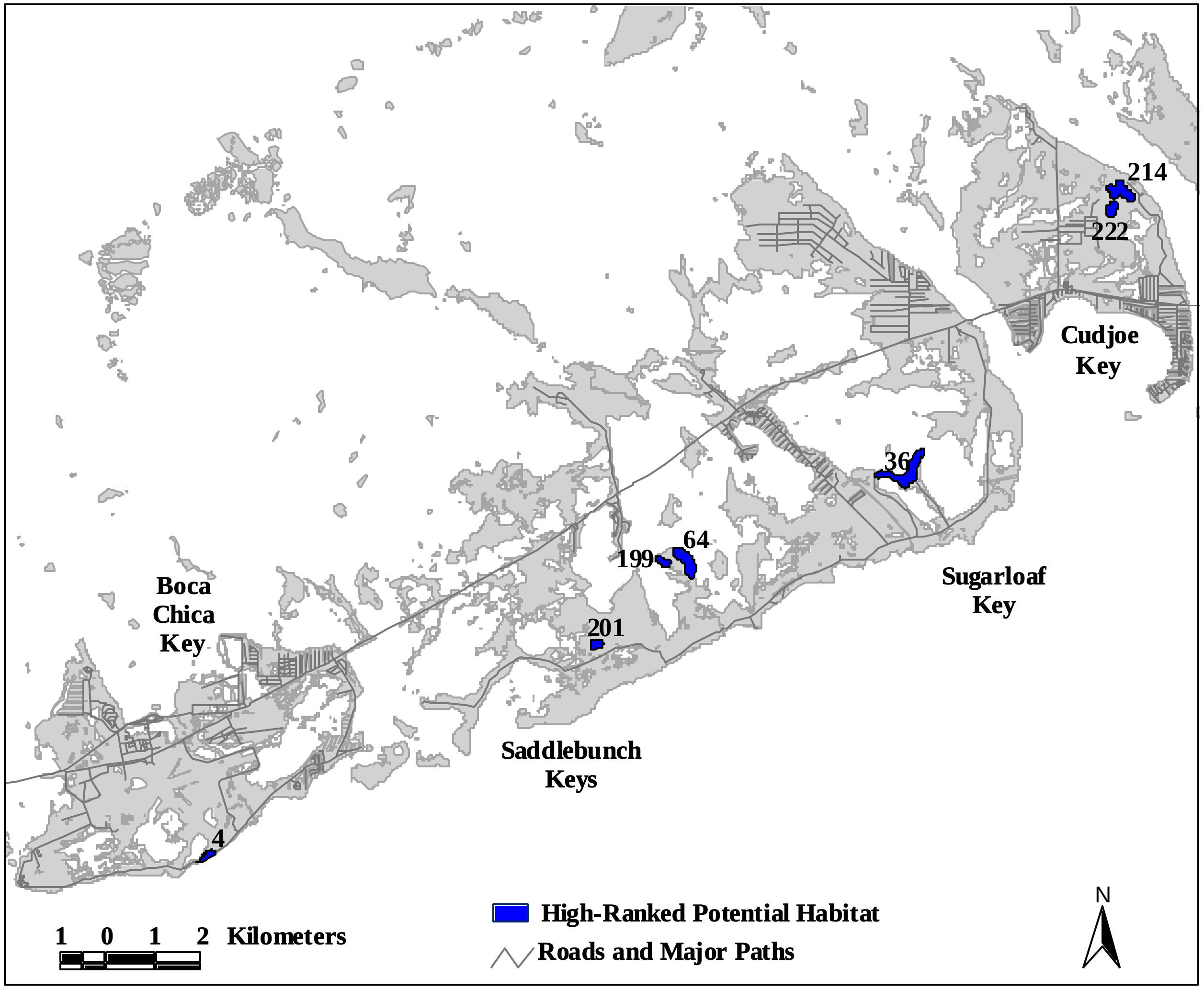

Fig. 4.6. Potential Lower Keys marsh rabbit populations from Boca Chica to Cudjoe Key that received the highest ranking in a Potential Habitat Score system from 2001–2003.

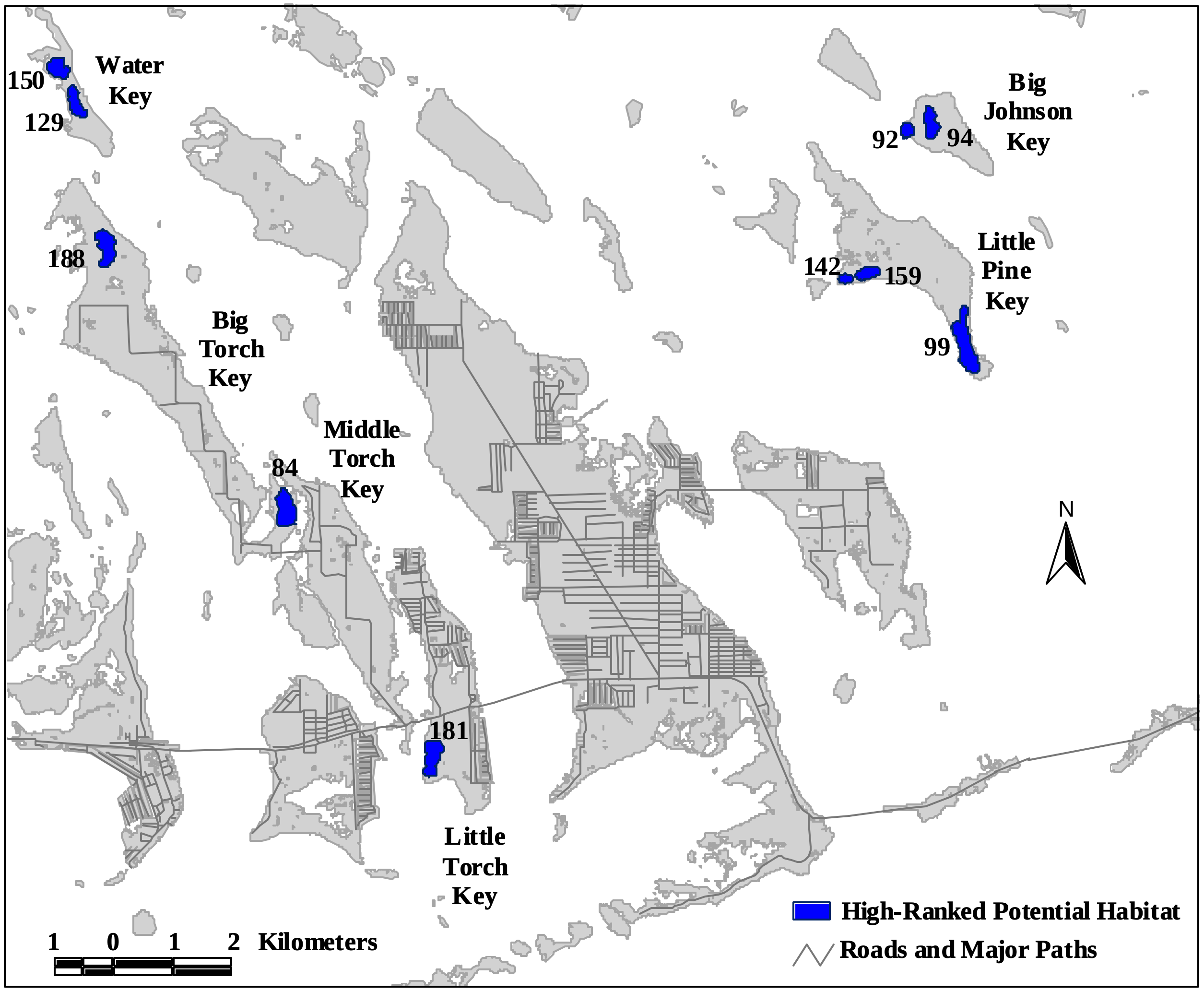

Fig. 4.7. Potential Lower Keys marsh rabbit populations from the Torch keys to Big Johnson Key that received the highest ranking in a Potential Habitat Score system from 2001–2003.

The criteria for distance to development (Table 4.3) were based on the estimated movements of free-roaming cats. Most studies of free-ranging cat movements have taken place in urban (e.g., Dards 1978, Haspel and Calhoon 1989) or rural (e.g., Liberg 1980, 1984; Warner 1985; Weber and Dailly 1998) settings or in isolated wild lands (e.g., Jones and Coman 1982, Konecny 1987, Edwards et al. 2001). The situation in the Lower Keys, however, most closely parallels that described by Barratt (1997), where free-ranging cats resided in a suburban development and rural residences adjacent to wild lands. The mean of the maximum distance moved from human habitation for all cats in Barratt's (1997) study was 320 m. The maximum movement for any of the cats from human habitation was 940 m. These values were used to develop the criteria for distance to development in the Potential Habitat Score. A development grid was created based on the ADID GIS coverage, DOQQs, land parcel data from MCDPER, and knowledge of the area. Areas were classified as developed if they contained houses or other human structures. Large scarified areas, large areas of mowed vegetation, and roads were excluded. Distances to development were calculated for each potential population using a cost-distance grid.

Distance to roads was calculated using the same method described above for distance to development. Only paved roads were included in the analyses, as it was assumed the probability of LKMR mortality would be less on uneven dirt or gravel roads, where vehicles would have to travel more slowly. Thirty meters seemed a reasonable distance from roads to prevent rabbits from being threatened by vehicles during their normal daily activities (Table 4.3).

The TAPP-scale score and the landscape-scale score were averaged to attain an overall Potential Habitat Score (maximum score of 100) for each site. Potential populations with a TAPP score $\geq$ 69, a landscape score > 61, and a total score $\geq$ 75 were considered to be the most suitable for LKMRs.

Seventeen potential populations were judged to be the top-rated unoccupied areas (Table 4.4, Figs. 4.6–4.7). Fourteen of the areas are already under public or military ownership (Table 4.4). The remaining 3 potential populations are intersected by 9 privately owned parcels totaling 96 ha (Figs. 4.2–4.4). One of these parcels on Little Torch Key (20 ha), however, was owned by the Nature Conservancy and was protected. Rabbits have already been reintroduced to the 3 areas on Little Pine Key (Chapter III).

There are some improvements that could be made to the Potential-Habitat-Score system. First, patch-level criteria could be refined by studying relationships between habitat variables and population parameters such as density, survival, and reproduction (Van Horne 1983, Garshelis 2000). Second, the distance to development criterion could be improved by studying the movements and habitat use of feral and free-ranging domestic cats in the Lower Keys, as cat movements exhibit wide variation depending on the environment (Dards 1978, Jones and Coman 1982, Warner 1985, Apps 1986, Haspel and Calhoon 1989; see Liberg et al. 2000 for a review) and whether cats are feral or domestic (Liberg 1984).

Dispersal Areas.-- Privately-owned, undeveloped parcels located between occupied and top-ranked potential populations and their neighboring patches were identified using land parcel data from MCDPER

(Figs. 4.8–4.11). On the Saddlebunch Keys and Big Pine Key, all occupied populations are connected by continuous parcels of publicly owned land. On Sugarloaf Key, however, populations are connected to some neighbors by only undeveloped, privately-owned lots. For 10 out of the 16 top-rated areas, corridors to neighbors ran through continuous stretches of publicly owned land. Others, such as potential populations 64 and 199 in the Saddlebunch Keys and 36 on Sugarloaf Key, would require land acquisition to ensure connectivity to neighbors.

Remaining Potential Populations.-- Forty and 7% of the remaining potential populations entirely occurred on publicly-owned land and land owned by the U.S. military, respectively. Seventeen and 35% occurred on privately-owned land and land with a mixture of public and private lots, respectively. These potential populations intersected with 855 privately-owned, undeveloped parcels (590 ha) (Figs. 4.1–4.5). Eight of these (52 ha) are owned and protected by TNC. Furthermore, 21 parcels (65 ha) with <50% development intersected with the remaining potential populations. Purchasing some of the privately-owned lots between these potential populations and their neighbors would ensure connectivity (Figs. 4.8–4.11).

Summary of Land Ownership.-- Overall, 40% of OPLPs, encompassing 32% of patches, occurred entirely on non-military, publicly-owned land (Figs. 4.12–4.18). An additional 19% of OPLPs, encompassing 24% of patches, were entirely on land owned by the U. S. military, primarily NAFKW. Thus, just over half of the OPLPs have been protected from private development. However, 41% of OPLPs occurred on either privately owned land or land with a mix of private and public parcels (Figs. 4.12–4.18). The mapped borders of OPLPs intersected with 1,306 undeveloped, privately owned parcels and 28 privately owned parcels with < 50% development (Figs. 4.1–4.5). Twenty-five of these parcels (93 ha) were protected by the Nature Conservancy. Acquiring the remainder of the parcels would require the purchase of 1,078 ha of undeveloped land and 119 ha of partially developed land. Additional parcels would need to be purchased to ensure connectivity between patches.

Tier System

Most LKMR habitat and possible dispersal areas were slated for acquisition under the proposed Tier system. Ninety-seven percent of the privately owned, undeveloped parcels intersecting all OPLPs were classified by MCDPER as Tier 1. The remaining 3% should be re-classified as Tier 1 (Figs. 4.19–4.20). All except 2 occupied populations are connected to their neighbors by undeveloped Tier 1 parcels or land owned by the U. S. military. The 2 exceptions, populations 31 and 32, are connected to one another by Tier 1 parcels but are isolated from neighbors by pre-existing human development and channels between islands. All of the top-rated unoccupied areas were connected to neighbors via continuous parcels of undeveloped Tier 1 land, and all of the other potential populations were connected to $\geq$1 neighbor by continuous Tier 1 parcels.

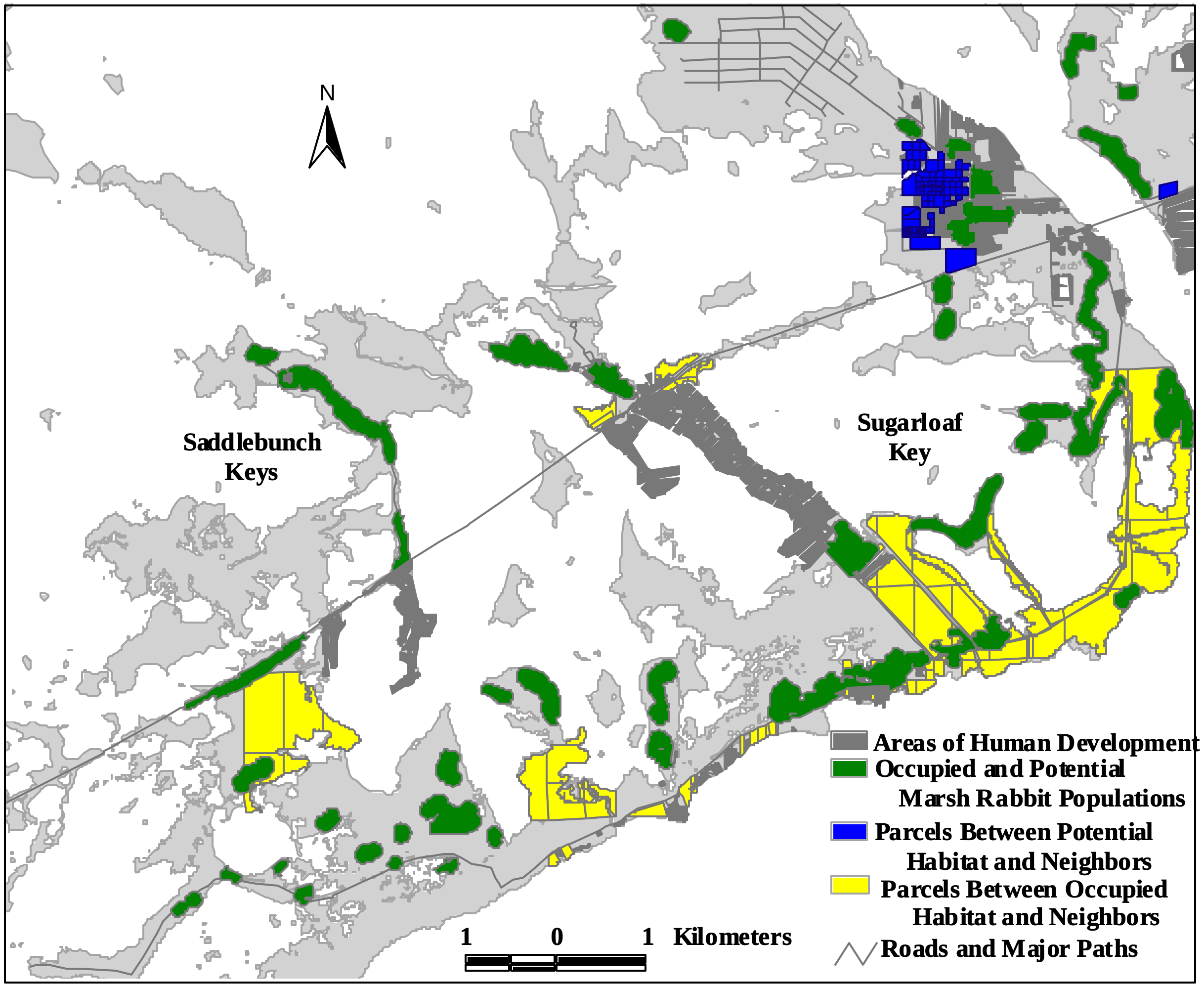

Fig. 4.8. Undeveloped, privately-owned parcels located between occupied and potential Lower Keys marsh rabbit populations and neighboring occupied and potential populations on Sugarloaf and the Saddlebunch keys from 2001–2003.

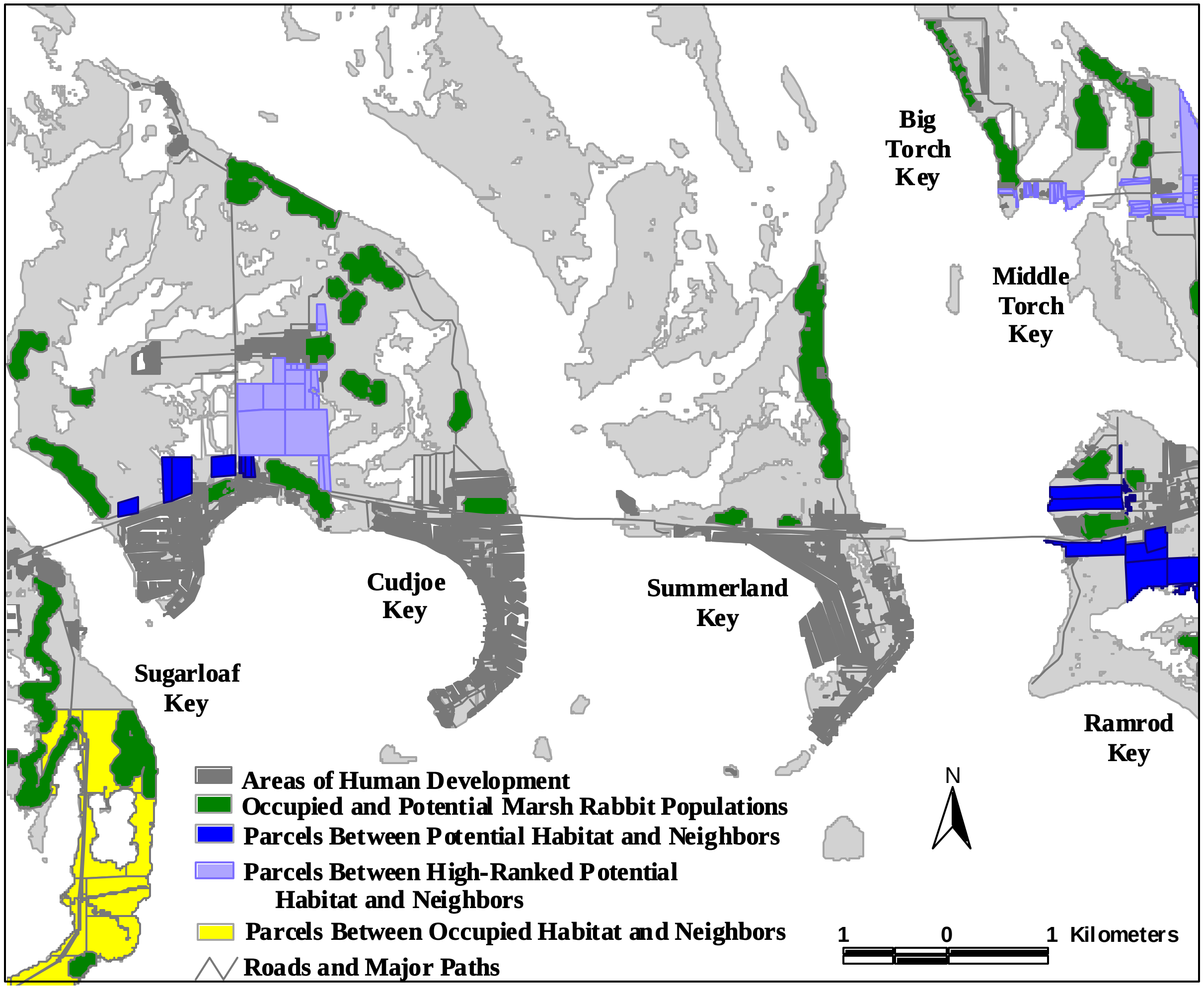

Fig. 4.9. Undeveloped, privately-owned parcels located between occupied and potential Lower Keys marsh rabbit populations and neighboring occupied and potential habitat on Cudjoe Key and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys from 2001–2003. Parcels connecting potential habitat that received a high Potential Habitat Score to neighboring habitat are distinguished from parcels surrounding other potential habitat.

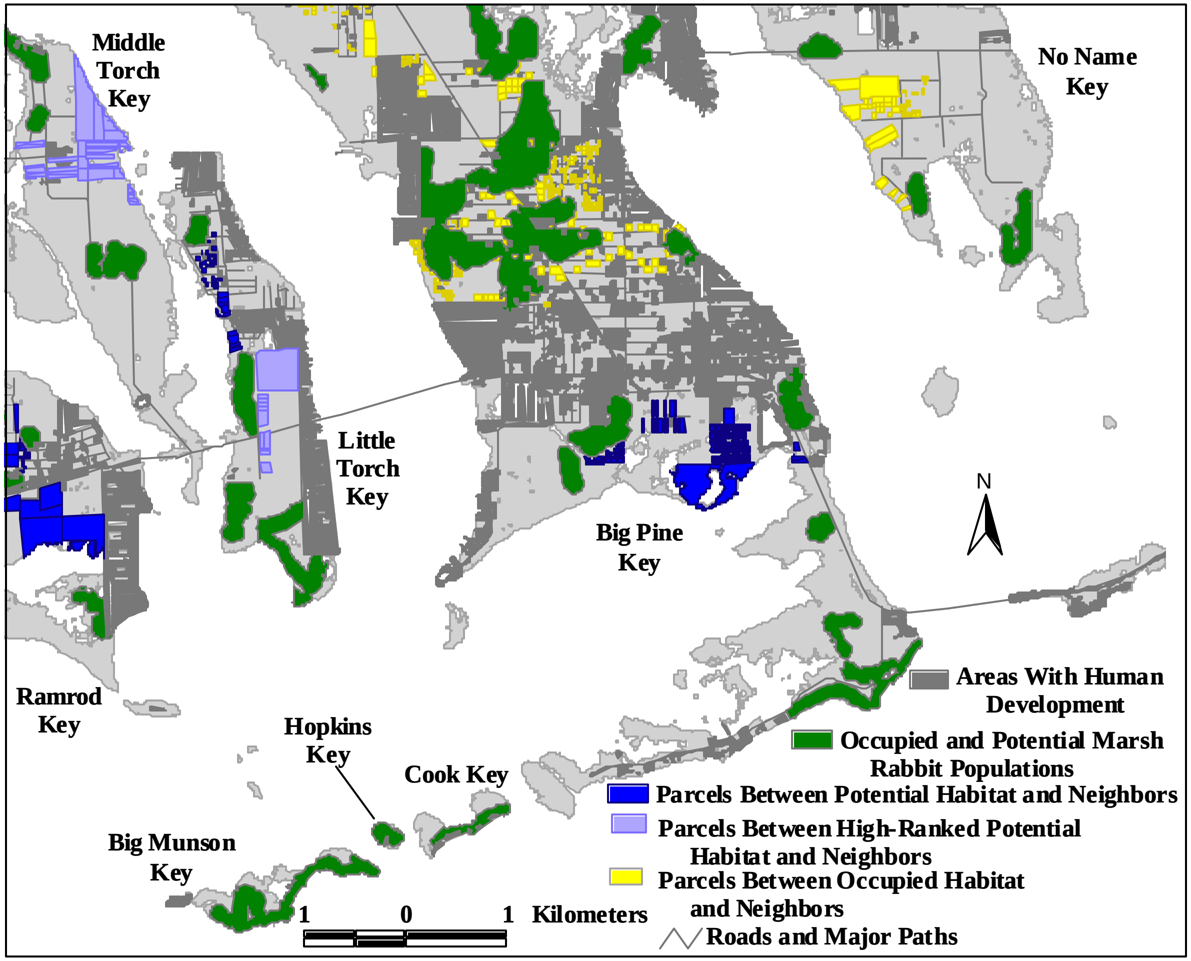

Fig. 4.10. Undeveloped, privately-owned parcels located between occupied and potential Lower Keys marsh rabbit populations and neighboring occupied and potential habitat on Little Torch, Middle Torch, and No Name keys and portions of Big Pine and Ramrod keys from 2001–2003. Parcels connecting potential habitat that received a high Potential Habitat Score to neighboring habitat are distinguished from parcels surrounding other potential habitat.

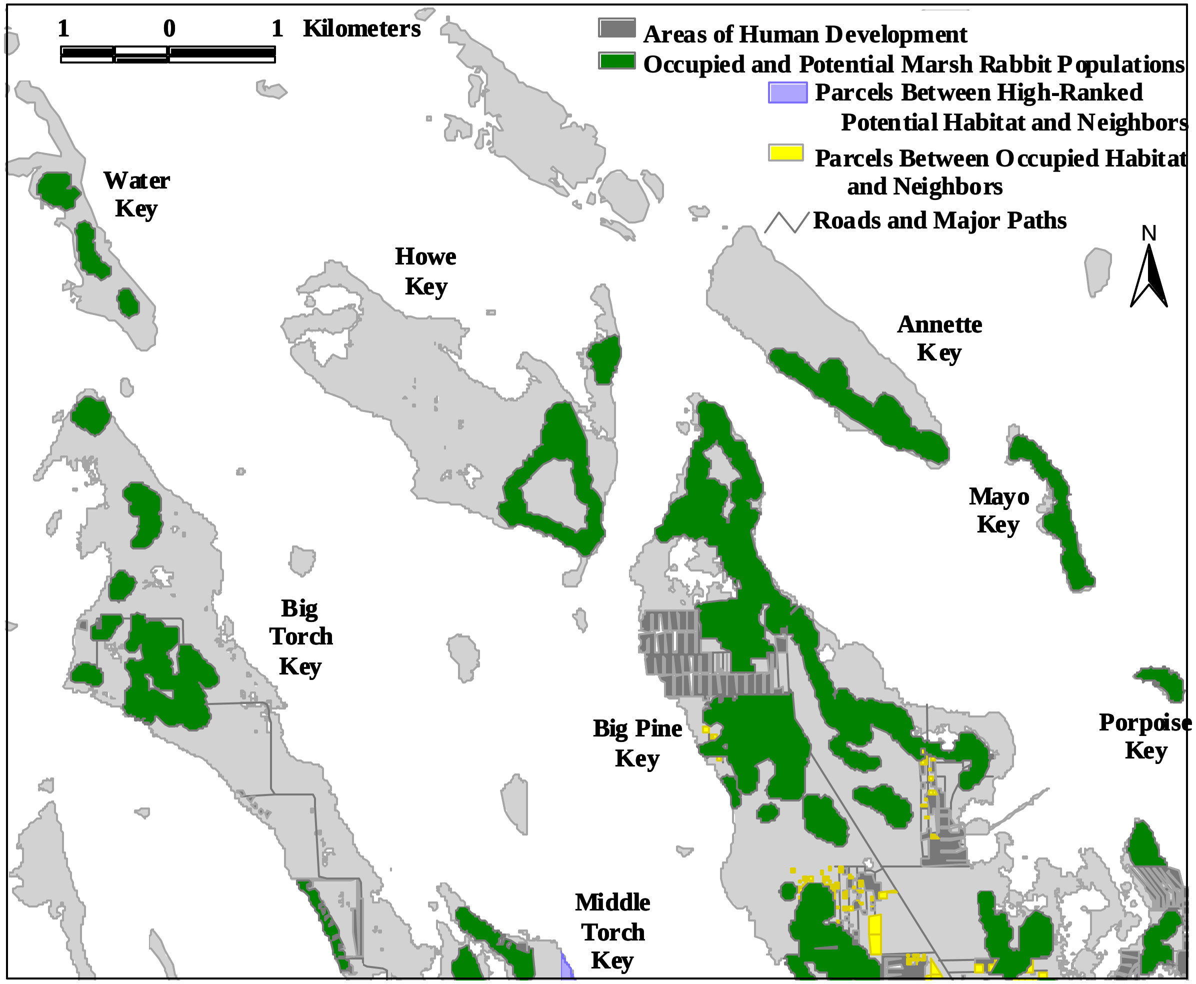

Fig. 4.11. Undeveloped, privately-owned parcels located between occupied and potential Lower Keys marsh rabbit populations and neighboring occupied and potential habitat on portions of Middle Torch and Big Pine keys from 2001–2003. Potential habitat on Middle Torch Key was one of the highest-ranked areas in a Potential Habitat Score system.

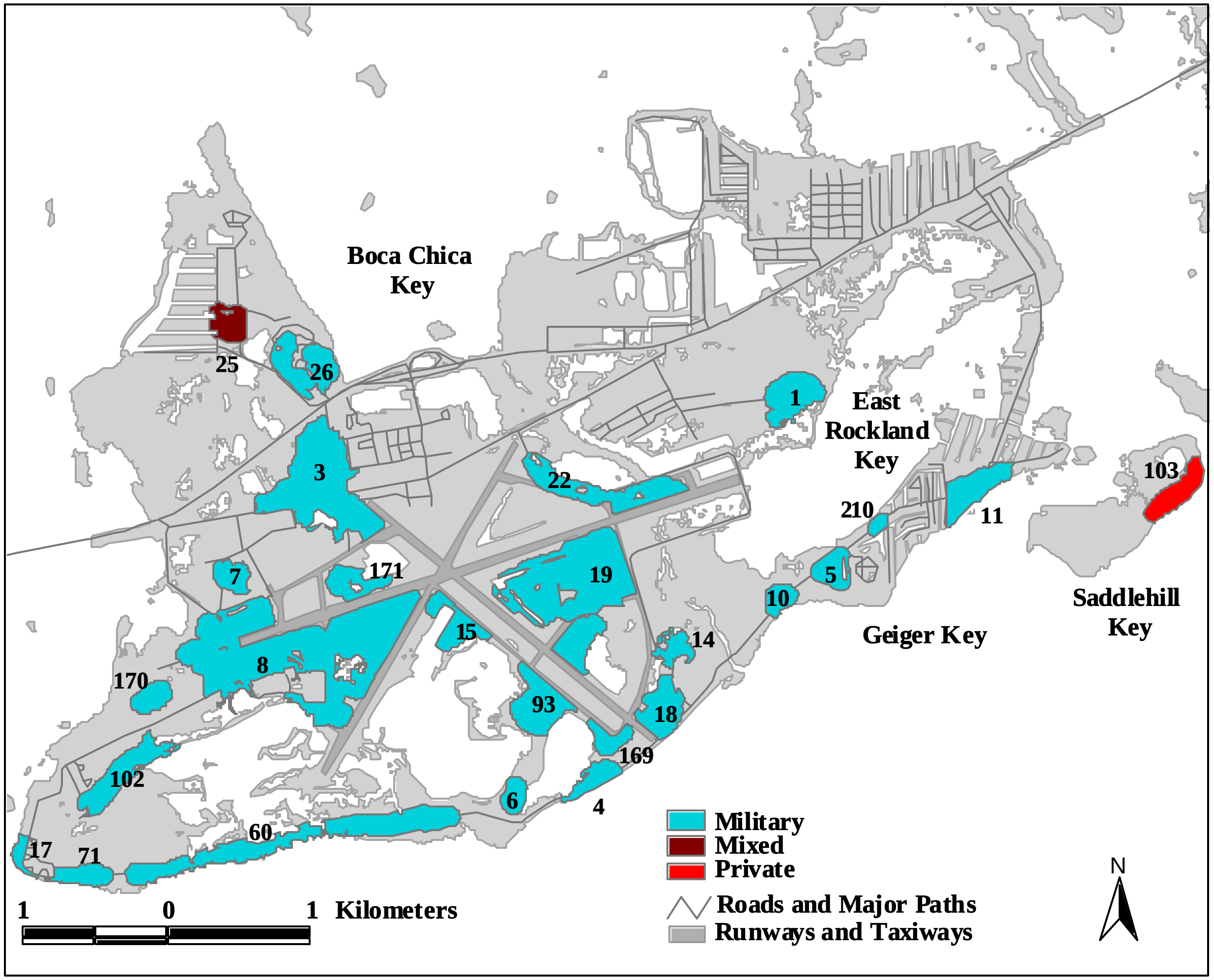

Fig. 4.12. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Boca Chica, East Rockland, Geiger, and Saddlehill keys from 2001–2003. “Mixed” ownership indicates a combination of privately- and publicly-owned parcels of land.

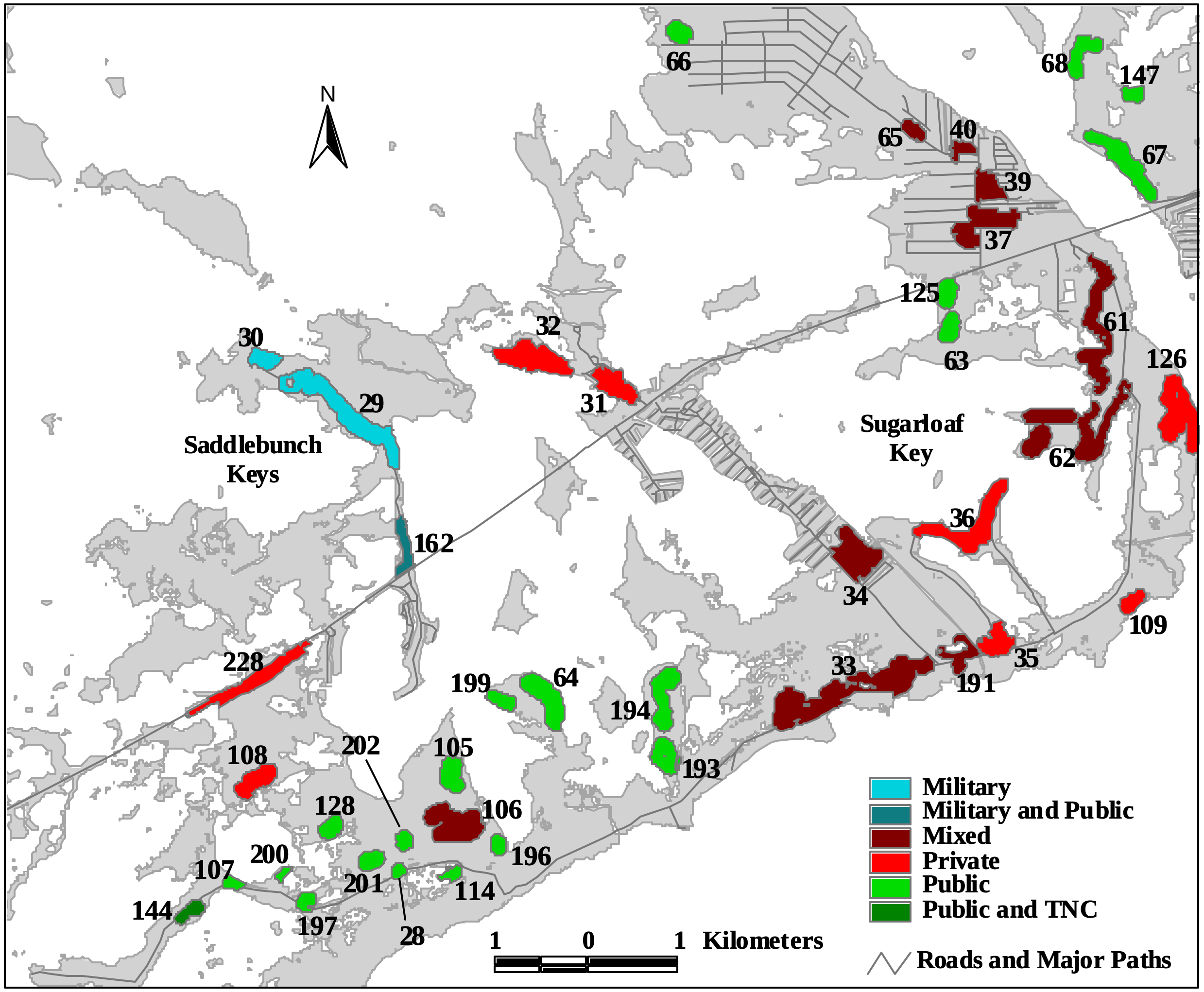

Fig. 4.13. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Sugarloaf and the Saddlebunch keys from 2001–2003. "Mixed" ownership indicates a combination of privately- and publicly-owned parcels of land. "TNC" refers to The Nature Conservancy.

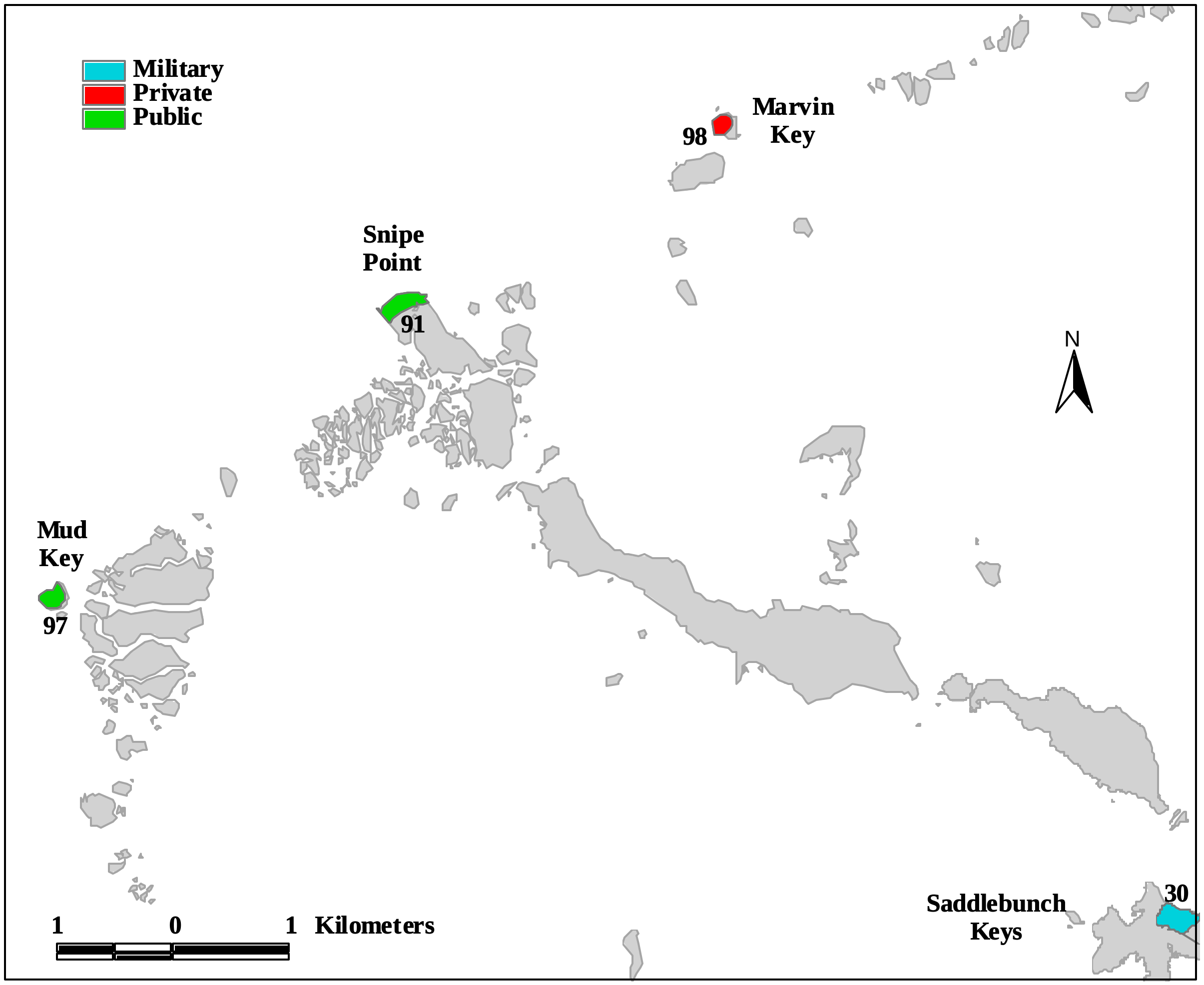

Fig. 4.14. Ownership of land within potential populations of the Lower Keys marsh rabbit on Mud, Snipe Point, and Marvin keys from 2001–2003.

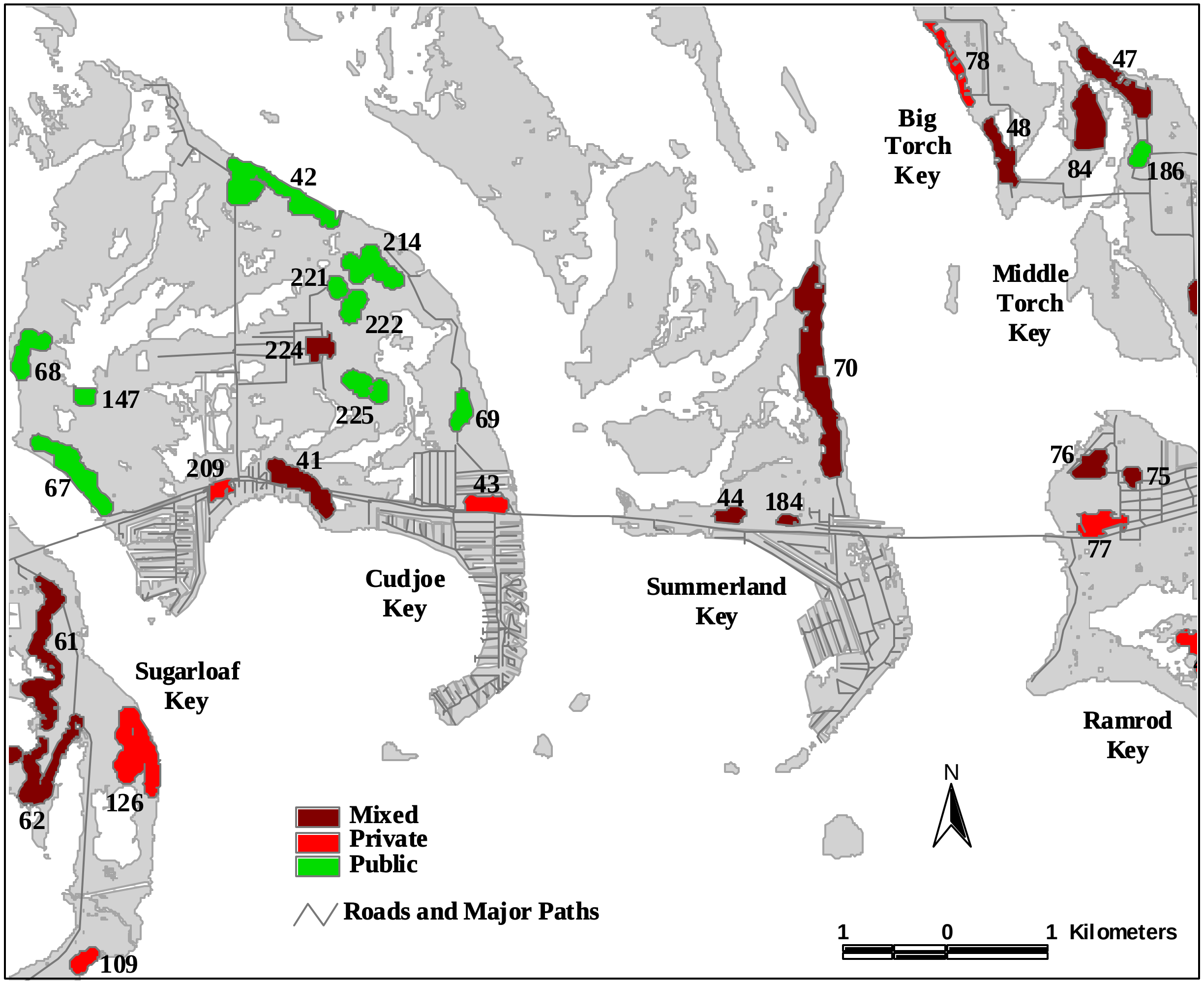

Fig. 4.15. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Cudjoe and Summerland keys and portions of Sugarloaf, Ramrod, Middle Torch, and Big Torch keys from 2001–2003. “Mixed” ownership indicates a combination of privately- and publicly-owned parcels of land.

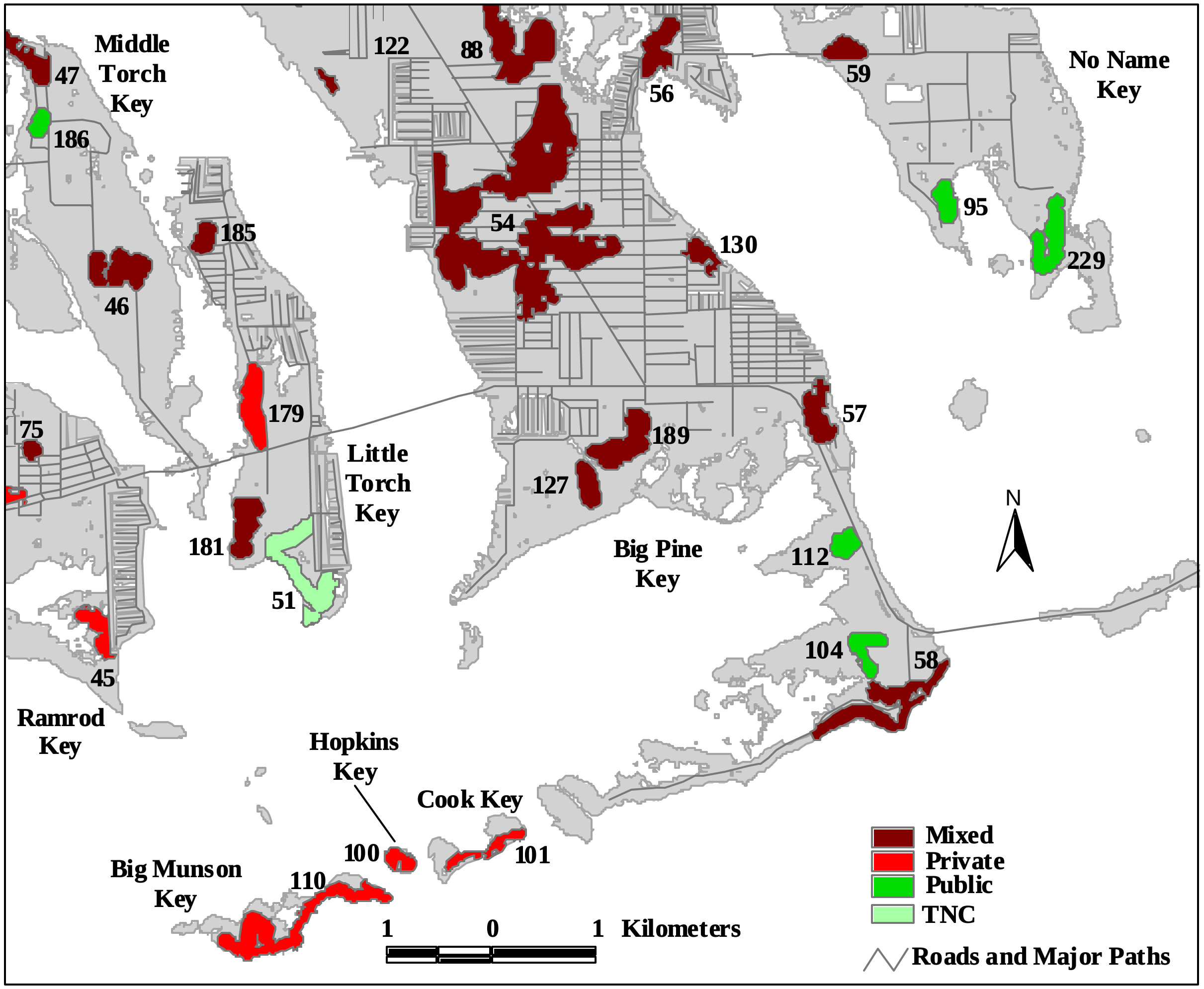

Fig. 4.16. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Little Torch, Big Munson, Hopkins, Cook, and No Name keys and portions of Big Pine and Middle Torch keys from 2001–2003. "Mixed" ownership indicates a combination of privately- and publicly-owned parcels of land. "TNC" refers to The Nature Conservancy.

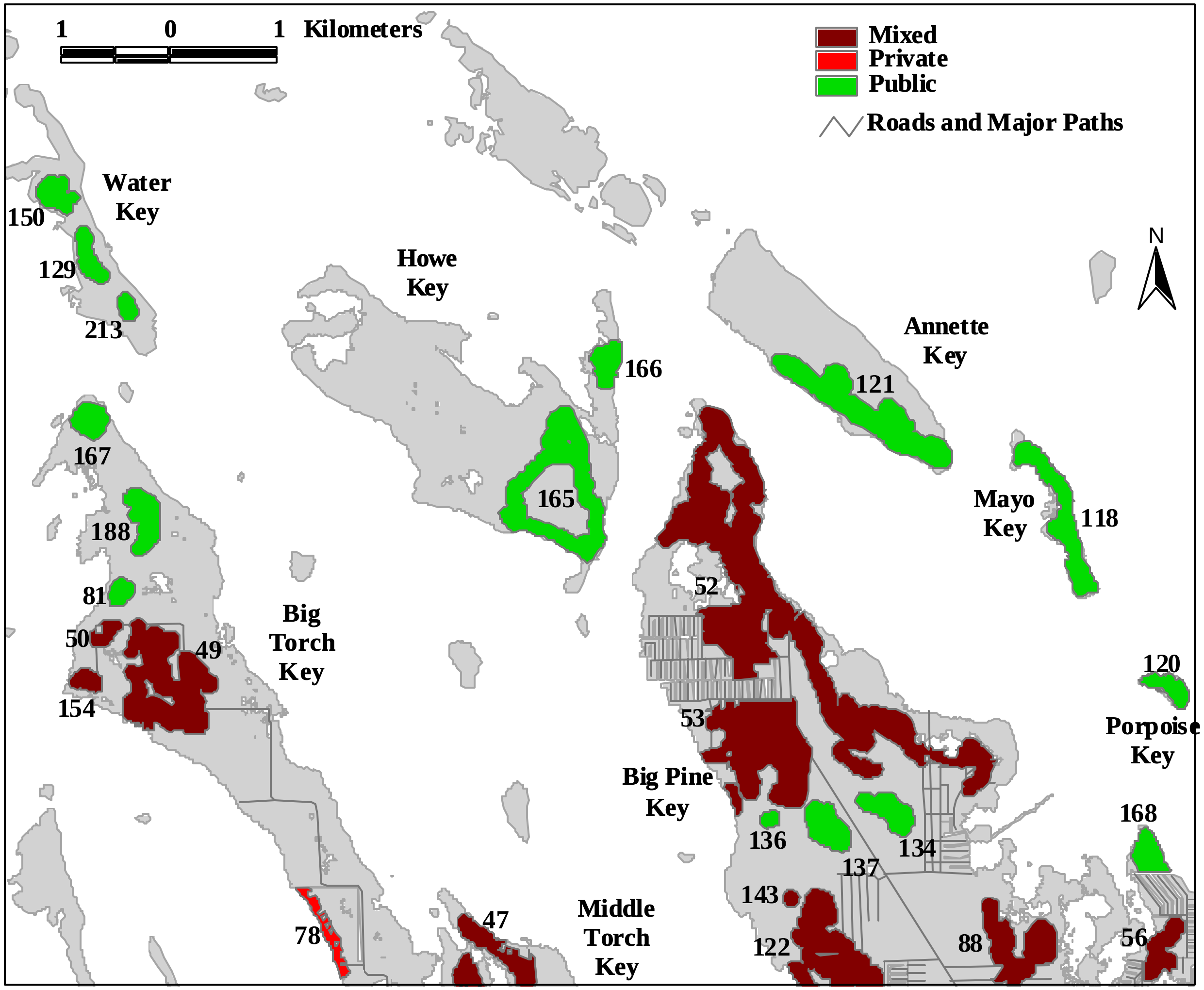

Fig. 4.17. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Big Torch, Water, Howe, Annette, Mayo, and Porpoise keys and a portion of Middle Torch and Big Pine keys from 2001–2003. “Mixed” ownership indicates a combination of privately- and publicly-owned parcels of land.

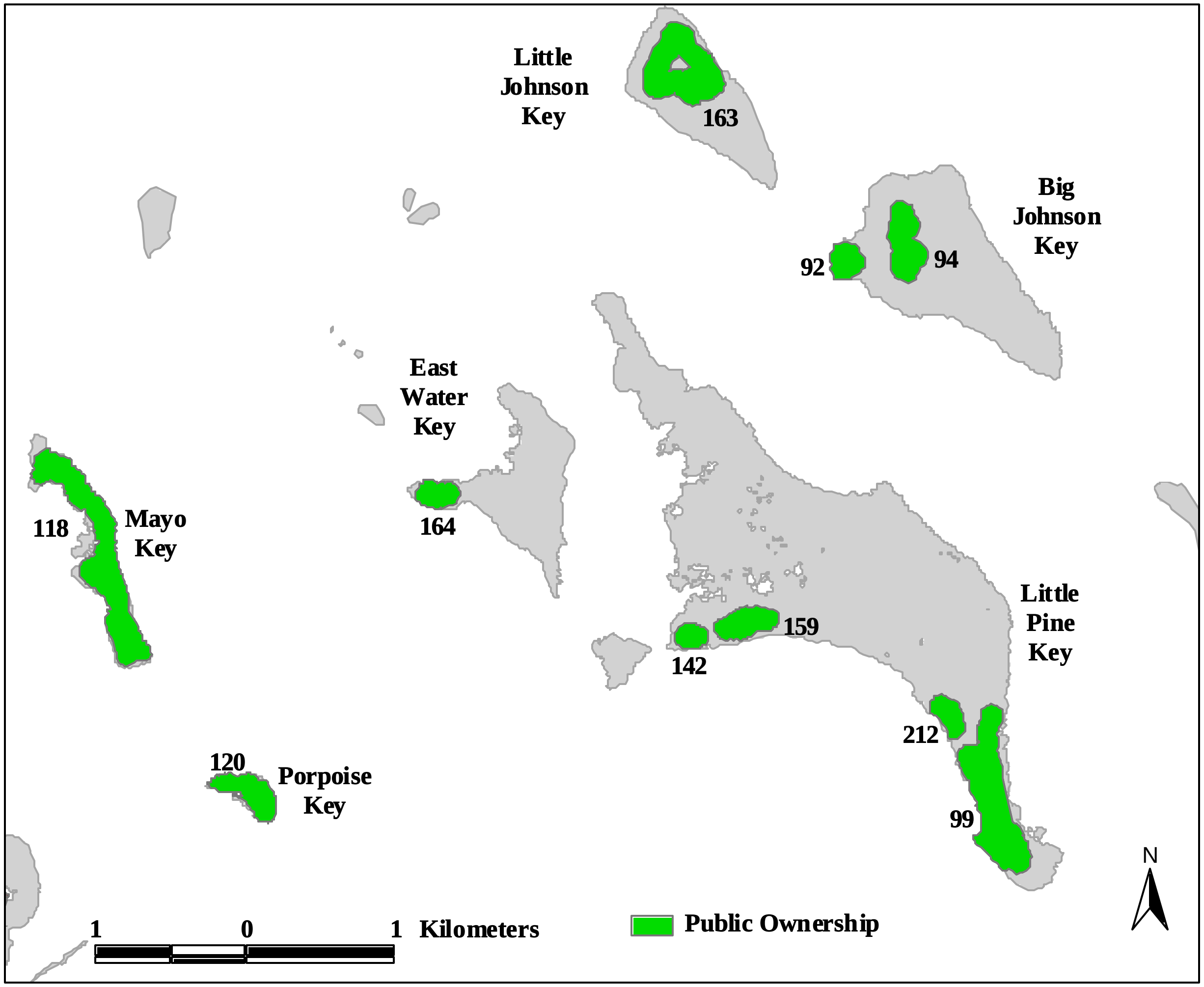

Fig. 4.18. Ownership of land within occupied and potential populations of the Lower Keys marsh rabbit on Mayo, Porpoise, East Water, Little and Big Johnson, and Little Pine keys from 2001–2003.

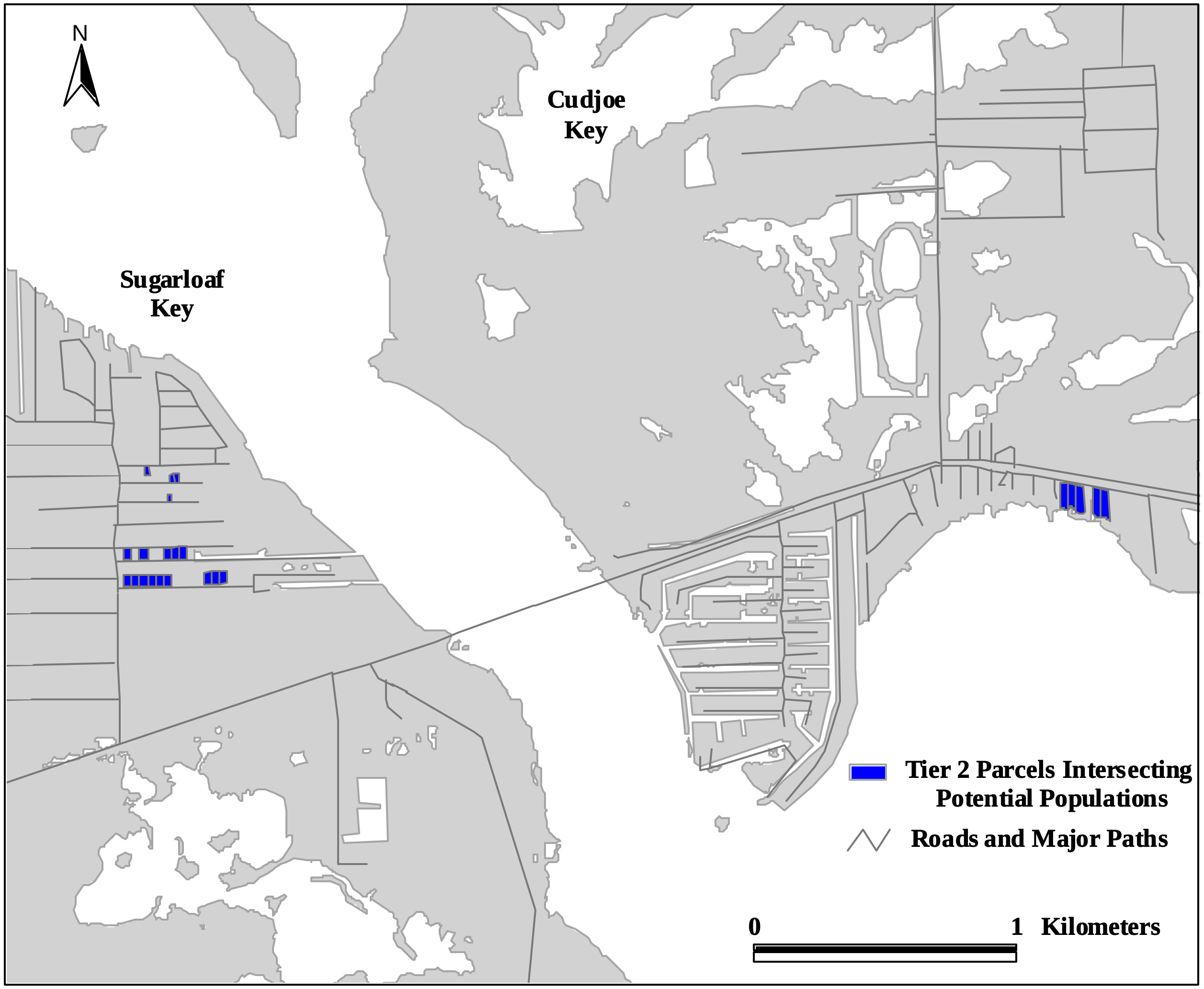

Fig. 4.19. Parcels designated as Tier 2 by the Monroe County Department of Planning and Environmental Resources that intersect with potential Lower Keys marsh rabbit populations on Sugarloaf and Cudjoe keys in 2003.

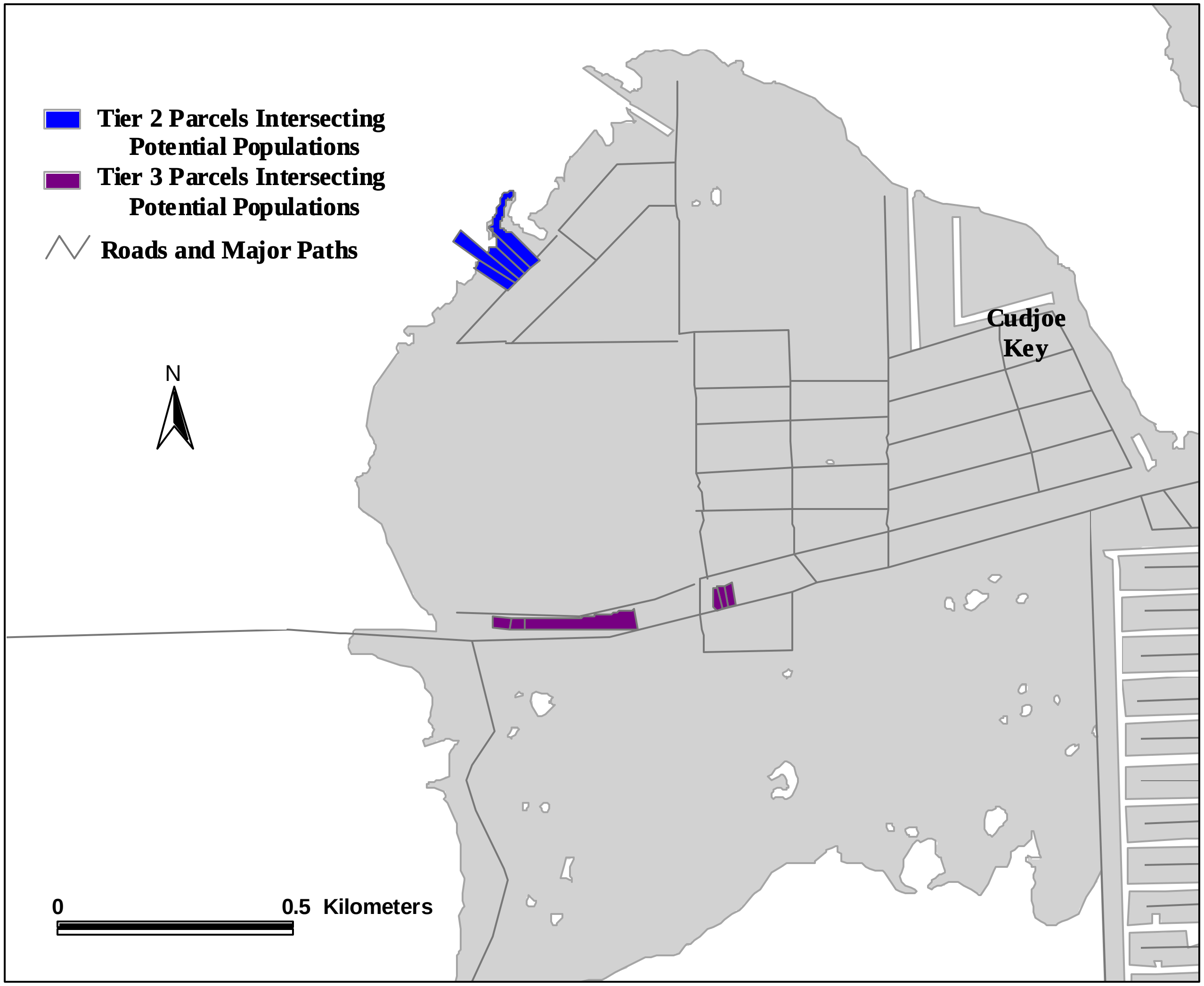

Fig. 4.20. Parcels designated as Tier 2 and 3 by the Monroe County Department of Planning and Environmental Resources that intersect with potential Lower Keys marsh rabbit populations on Ramrod Key in 2003.

REINTRODUCTION

Identification of Release Sites.-- The potential benefits of reintroduction have been discussed elsewhere in this thesis (Chapter III). I used the Potential-Habitat-Score system, described above, to identify potential reintroduction sites. The scoring system appeared to produce realistic results and, with the possible exception of potential population 92, did not give high ranks to any patches that were obviously unsuitable for reintroduction. Areas subjectively considered quality release sites were generally ranked high. Below, I discuss the potential of each of the top-ranked areas as a reintroduction site.

Potential populations 4 on Boca Chica Key and 201 in the Saddlebunch Keys were unoccupied during my surveys, but they appear to have suitable habitat and were in close proximity to occupied populations (Fig 4.6). Perhaps these areas were unoccupied simply by chance at the time of the surveys, though it is possible other unknown factors are preventing LKMRs from persisting in these sites. Under either scenario, these 2 areas should not be considered potential reintroduction sites.

Rabbits have already been reintroduced to Little Pine Key, which contained 3 of the 4 highest ranked patches (Chapter III). The third- and fifth-highest ranked patches occurred on Water Key, which has the advantage of being publicly-owned and completely isolated from human habitation (Fig 4.7). The disadvantages of Water Key include its isolation from neighbors and the fact that the patches encompass only 4.3 ha. Water Key is an interesting test case. In isolation, it is similar to Mayo and Annette keys, which have been consistently occupied by rabbits in the previous and current surveys despite a relative lack of bunchgrasses and the prevalence of intertidal and low grassy saltmarsh. Water Key has more bunchgrasses than these islands, but less total habitat. Rabbits may thrive on Water Key and provide a valuable learning experience about LKMR habitat use on small islands. On the other hand, it also is possible Water Key might be able to support relatively few rabbits, necessitating occasional restocking to counteract demographic and environmental stochasticity and to prevent inbreeding depression. Similar to Water Key, a reintroduction to Big Johnson Key would carry some risks. The patches on Big Johnson Key total only 3.9 ha and possess far fewer bunch grasses than Water Key.

Potential population 188 on Big Torch Key would make an excellent release site (Fig. 4.7). The patch is publicly-owned and encompasses 5.4 ha. Within 3 km of the patch, there are only 2 houses and enough potential habitat for 5 potential populations. Some of the neighboring patches have privately owned lots that need to be purchased. From potential population 188, LKMRs could colonize the entire northern portion of Big Torch Key.

Reintroducing rabbits to potential populations 84 and 181 could lead to the colonization of portions of Little Torch, Middle Torch, and Big Torch keys (Fig 4.7). However, these potential populations and their neighbors are more susceptible to secondary impacts from human development than other potential reintroduction sites.

Potential populations 214 and 222 seem promising due to their resemblance to some occupied freshwater marsh and freshwater hardwood patches on Big Pine Key (Fig. 4.6). However, the total area of the patches and the size of each individual patch are small compared to areas on Big Torch Key. Given the dearth of adjacent suitable saltmarsh/buttonwood transition zone habitat, managers should seek to avoid dry-season fires following the reintroduction, as these fires could pose a threat to the rabbit's persistence in this area following reintroduction.

Potential populations 64 and 199 in the Saddlebunch Keys and 36 on Sugarloaf Key have few neighbors in close proximity, though all are isolated from cars and cats (Fig. 4.6). If the land is purchased, potential population 36 would be preferred due to its larger size and, therefore, greater likelihood of persistence.

In summary, I recommend reintroducing LKMRs to potential population 188 on Big Torch Key, provided potential issues with private land owners to the south are addressed. Potential populations on Water Key, potential population 36 on Sugarloaf Key, and potential populations 214 and 222 on Cudjoe Key carry more risk but could prove successful. It also is worth noting that future management actions may enhance the suitability of some potential populations. For example, control of cats and perhaps habitat enhancement (see below) would make population 70 on Summerland Key an intriguing reintroduction site due to its large size.

Translocation Protocols.-- Managers should follow the translocation protocols described in this thesis (Chapter III). The probability of success could be maximized by establishing an *in-situ*-captive-breeding facility to provide founders (Chapter III).

SECONDARY IMPACTS FROM DEVELOPMENT

Direct impacts from development (e.g., habitat loss and fragmentation) were thought to be the primary historical cause for the decline of the LKMR (USFWS 1999). However, considering most LKMR habitat is either publicly-owned or has been placed in MCDPER's Tier 1 classification, secondary impacts from development may represent the greatest long-term threat to persistence of the LKMR metapopulation. Several possible secondary impacts are discussed below.

Feral and Domestic Cats

Feral and free-ranging domestic cats prey on rabbits throughout the world, and rabbits tend to make up a large proportion of prey items on islands (Apps 1983, Liberg 1985, Warner 1985, Molsher et al. 1999, see Fitzgerald and Turner 2000 for a review). Cats are known predators of LKMRs (Howe 1988, Forys 1995) and may have been responsible for half of the adult and subadult mortality observed by Forys (1995) on Boca Chica Key. During my study, cats were commonly seen in and around residential development in the Lower Keys. The objectives of this section were (1) to identify areas where existing or future development would be reasonably likely to result in secondary impacts from cats and (2) to suggest possible strategies for managing these impacts.

Site Identification.-- As in the Potential-Habitat-Score analyses above, 320 m (Barratt 1997) was used as a reasonable distance that cats would likely travel from human development. First, a cost-distance grid was created within 320-m of existing development to identify OPLPs that are reasonably likely to be impacted by cats. Second, a cost-distance grid was created within a 320-m radius of LKMR OPLPs, and developed and privately-owned undeveloped lots intersecting this grid were identified. A cost-distance grid was preferable to Euclidean distance measurements because the grid made it easier to account for barriers to cat movement (e.g., canals, bodies of water).

Thirty-one occupied populations are within 320 m of existing private development and may already have a feral or domestic cat problem (Figs. 4.21–4.25). Twelve of these populations are on NAFKW land on Boca Chica Key, where NAFKW has pledged to control cats (Department of the Navy, Southern Division Naval Facilities Engineering Command 2002) (Fig. 4.21). During a distribution survey from 2001–2003 (Chapter II), however, cats were seen in populations 157 and 18 on NAFKW. Eight hundred forty developed lots and 1,315 parcels of undeveloped, privately owned land, excluding properties owned by TNC, intersected the 320-m buffer around occupied populations (Figs. 4.26–4.35). Eighty-three percent of the undeveloped, privately owned lots within the buffers were designated as Tier 1, and 81% of these lots occurred on Big Pine Key. One hundred-nineteen undeveloped Tier 2 lots and 78 Tier 3 lots were found within the 320-m buffer on Big Pine, Sugarloaf, and the Saddlebunch keys.

Only 3 developed lots occurred within 320 m of highly-ranked potential populations (Fig. 4.29), and all of the undeveloped lots were designated as Tier 1. Potential populations 84 and 181 were within 320 m of existing development, though the ability of cats to reach potential population 84 may depend on their willingness to pass over water across mangrove prop roots. Sixty-three lots of undeveloped, privately-owned land were found within the 320-m buffer for high-ranked potential populations (Figs. 4.31–4.35).

Forty-six of the remaining potential populations were within 320-m of existing development (Fig. 4.21–4.25). There were 1,398 parcels of developed land and 300 parcels of Tier III land within the buffers. Undeveloped, privately-owned lots in Tiers I and II accounted for 1767 and 357 parcels, respectively.

In summary, 55% of occupied patches and 52% of potential populations were within 320 m of existing development and may be vulnerable to cats. The buffers included many private, undeveloped lots where future development would be reasonably likely to result in secondary impacts.

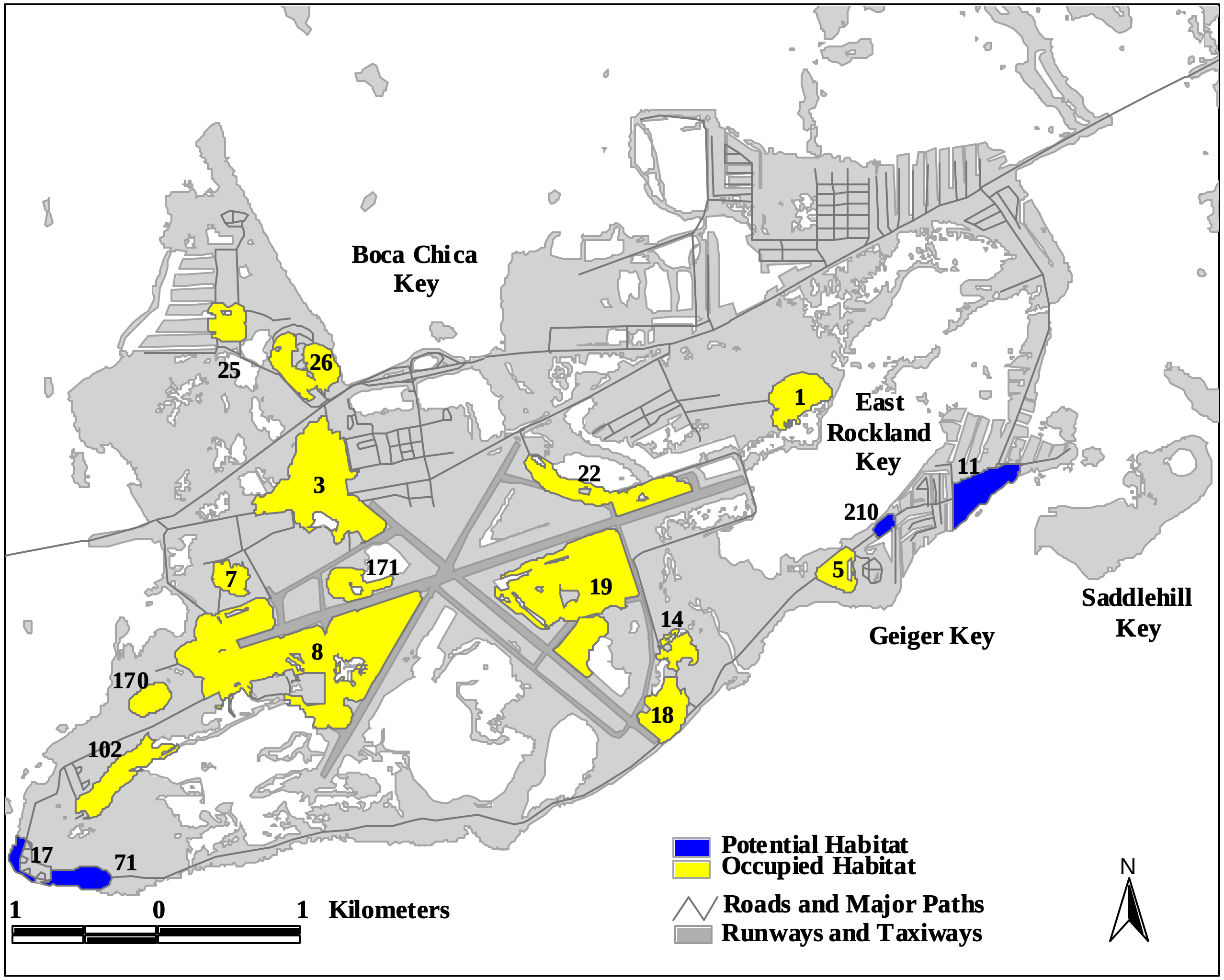

Fig. 4.21. Occupied and potential Lower Keys marsh rabbit populations within 320 m of human development (e.g., buildings, but not roads or runways) on Boca Chica, East Rockland, and Geiger keys from 2001–2003.

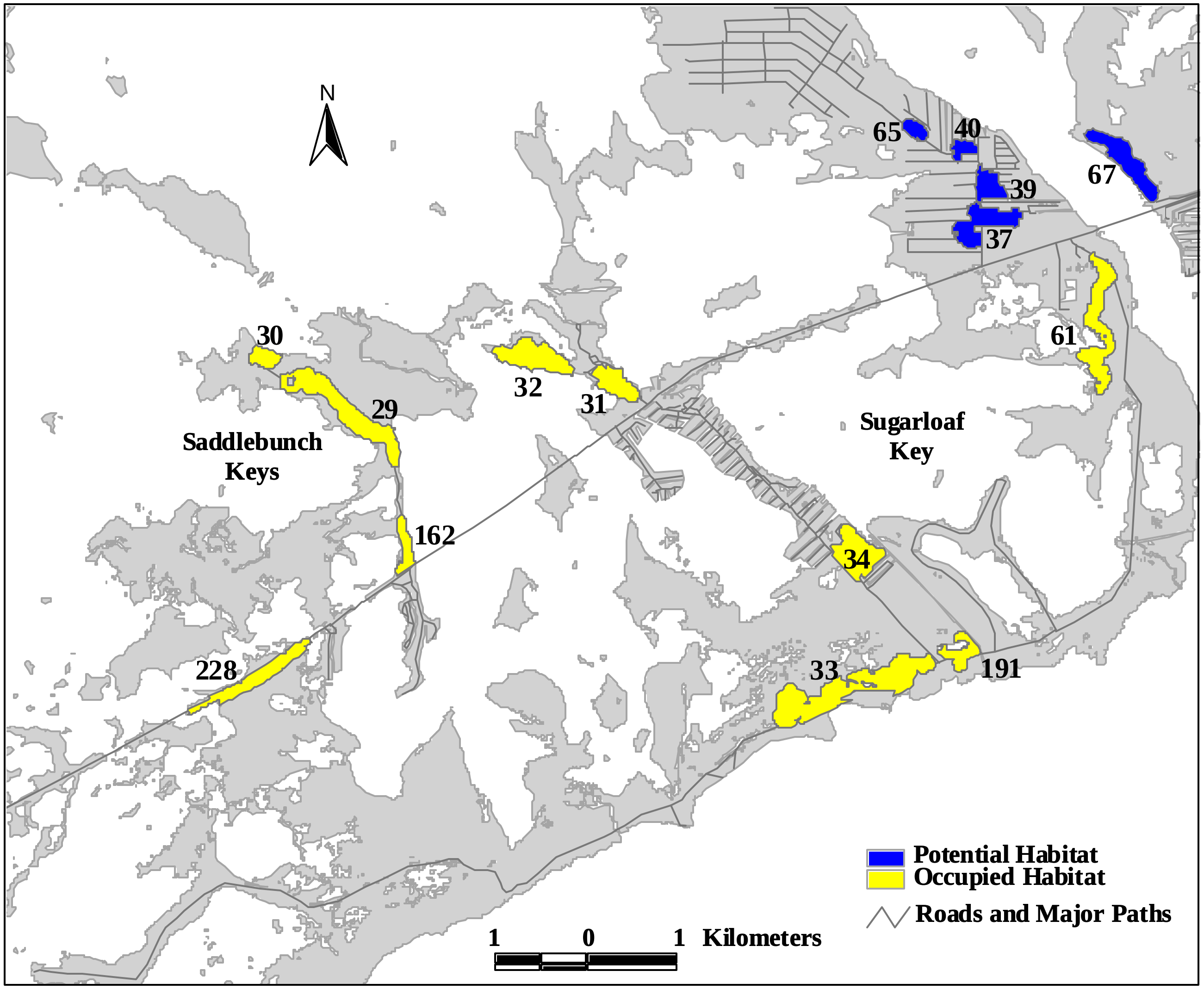

Fig. 4.22. Occupied and potential Lower Keys marsh rabbit populations within 320 m of human development (e.g., buildings, but not roads) on Sugarloaf and the Saddlebunch keys from 2001–2003.

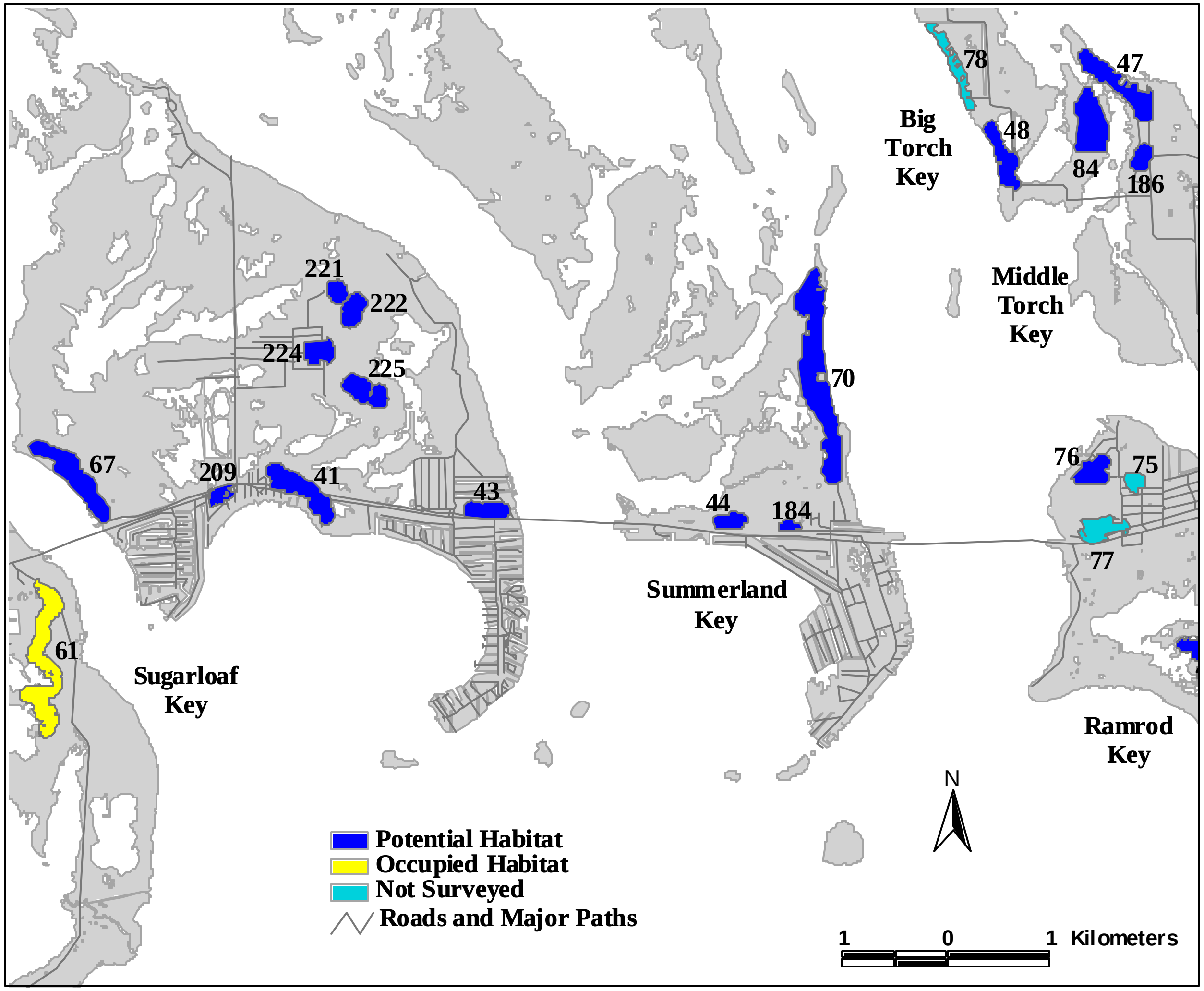

Fig. 4.23. Occupied and potential Lower Keys marsh rabbit populations within 320 m of human development (e.g. buildings, but not roads or runways) on Cudjoe and Summerland keys and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys from 2001–2003.

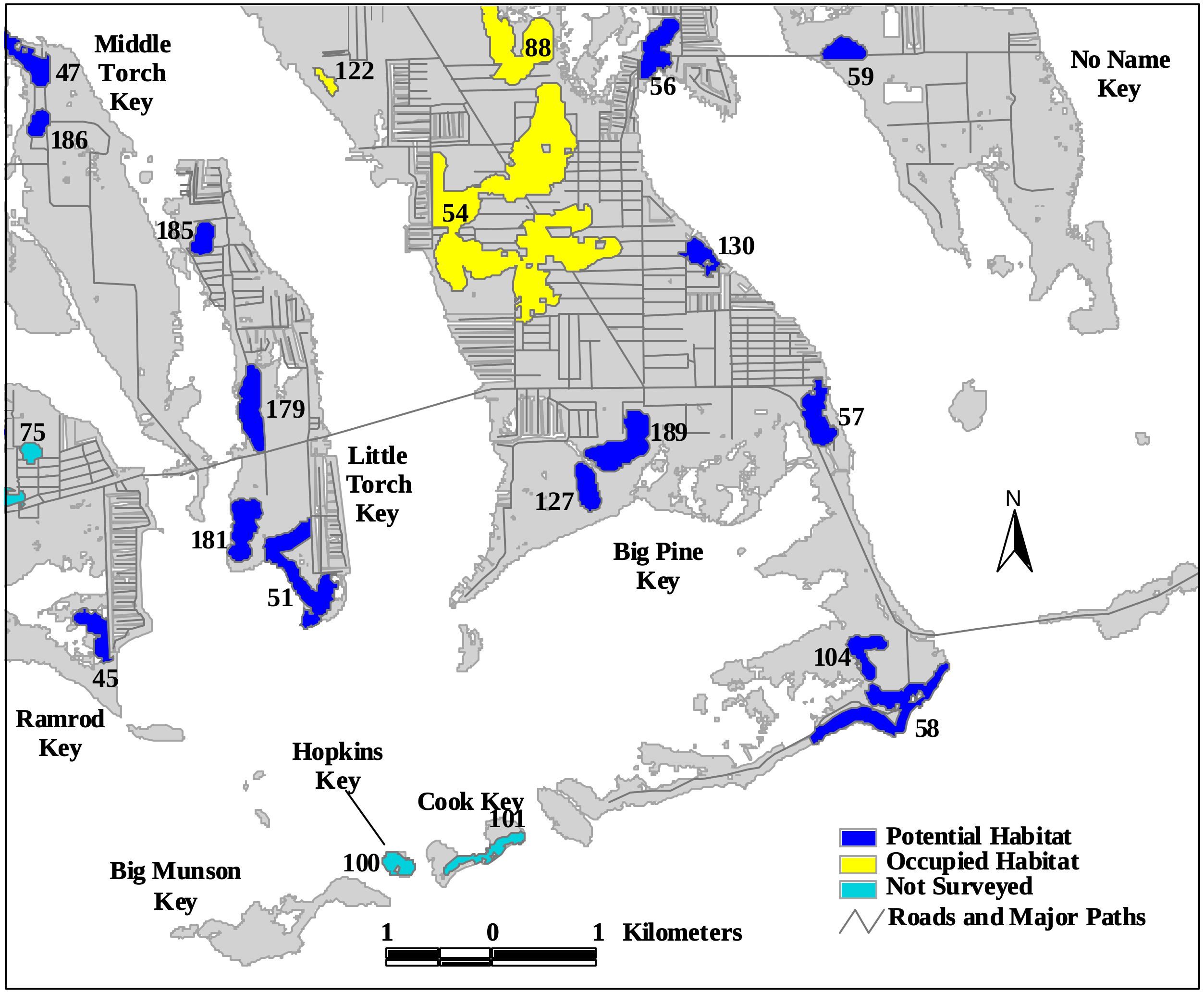

Fig. 4.24. Occupied and potential Lower Keys marsh rabbit populations within 320 m of human development (e.g. buildings, but not roads or runways) on Little Torch, Hopkins, Cook, and No Name keys and portions of Ramrod, Big Pine, and Middle Torch keys from 2001–2003.

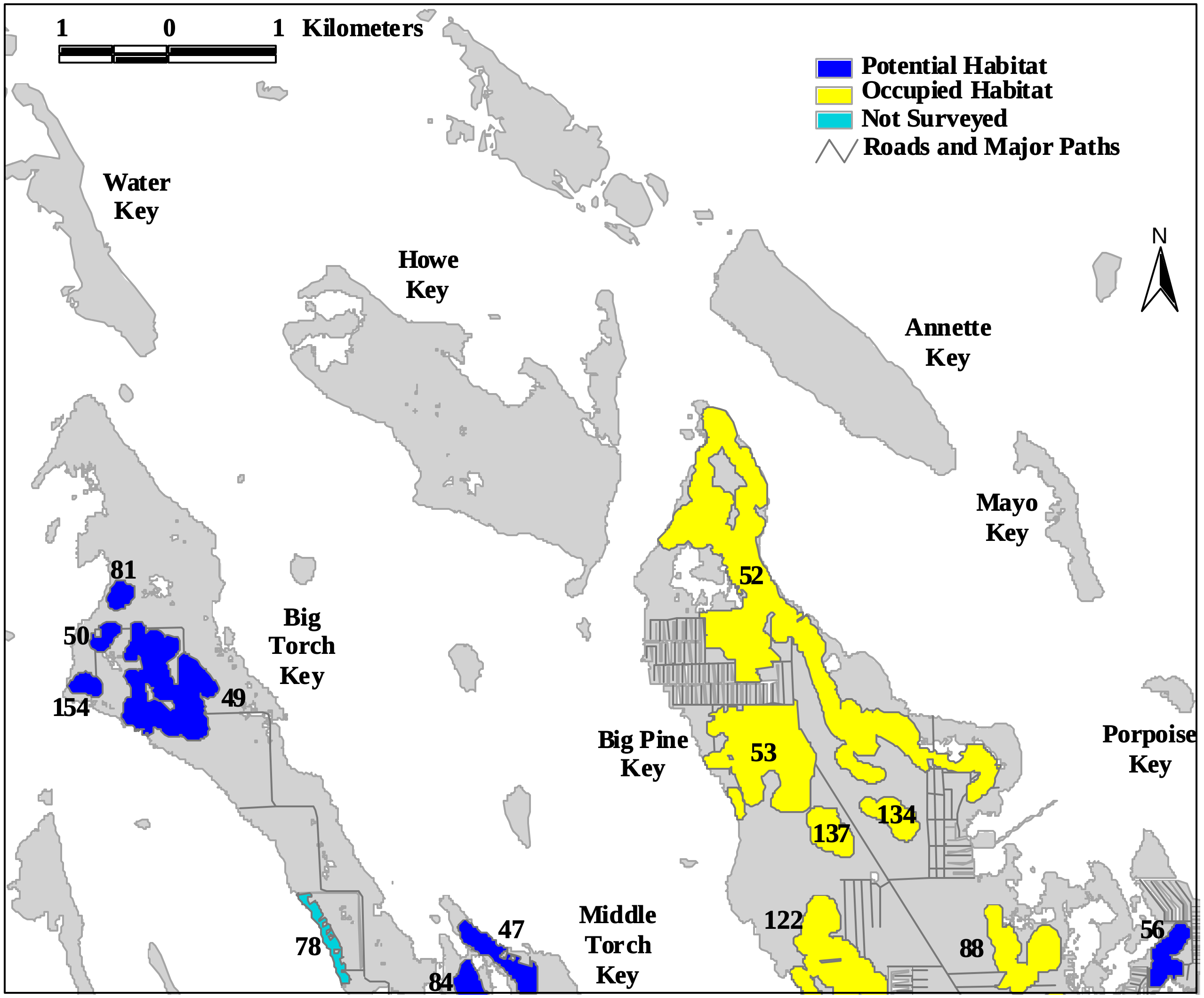

Fig. 4.25. Occupied and potential Lower Keys marsh rabbit populations within 320 m of human development (e.g. buildings, but not roads or runways) on Big Torch Key and a portion of Big Pine Key from 2001–2003.

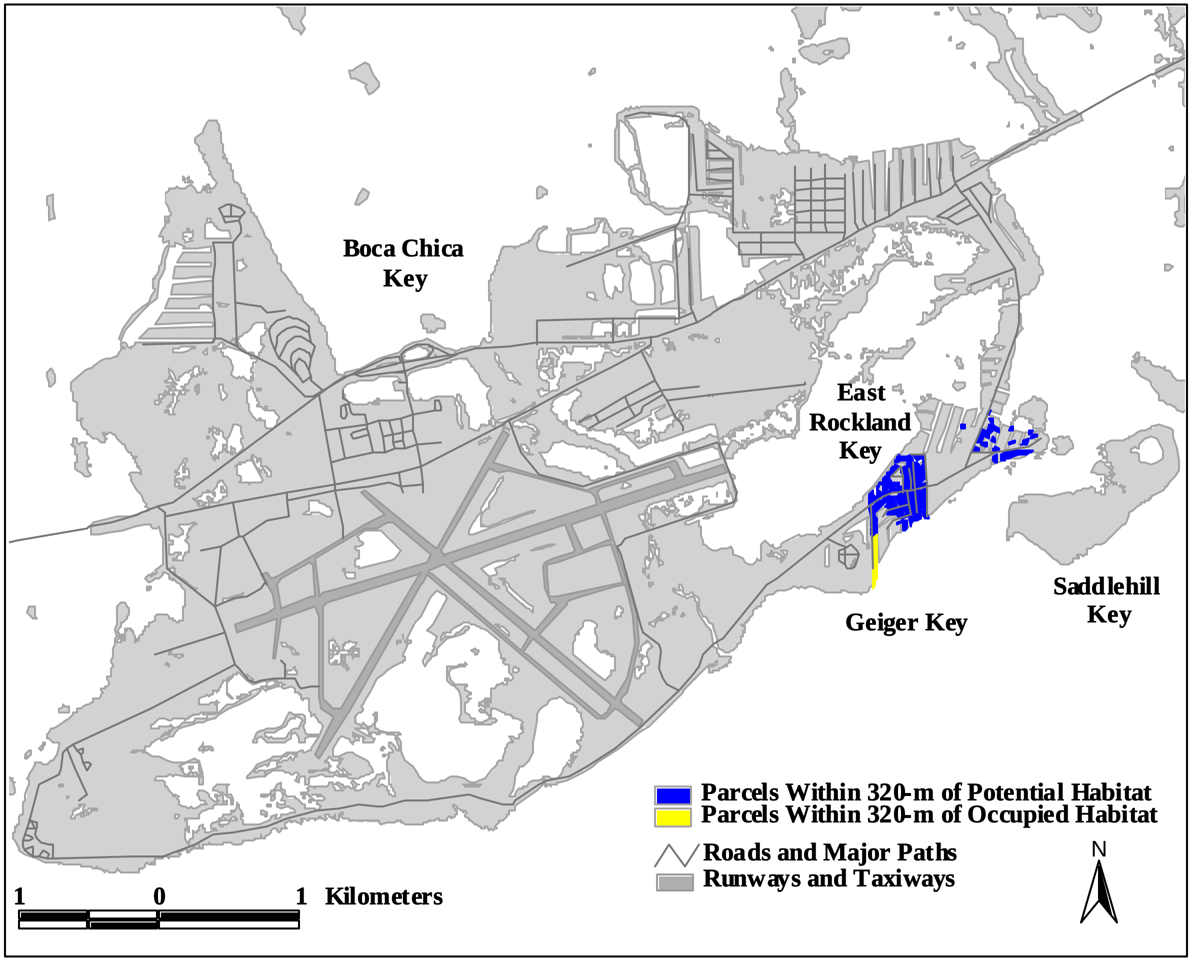

Fig. 4.26. Parcels of land with existing human development within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Boca Chica, East Rockland, Geiger, and Saddlehill keys in 2001–2003. Feral or free-roaming domestic cats on these properties would be reasonably likely to enter adjacent areas of occupied or potential rabbit habitat.

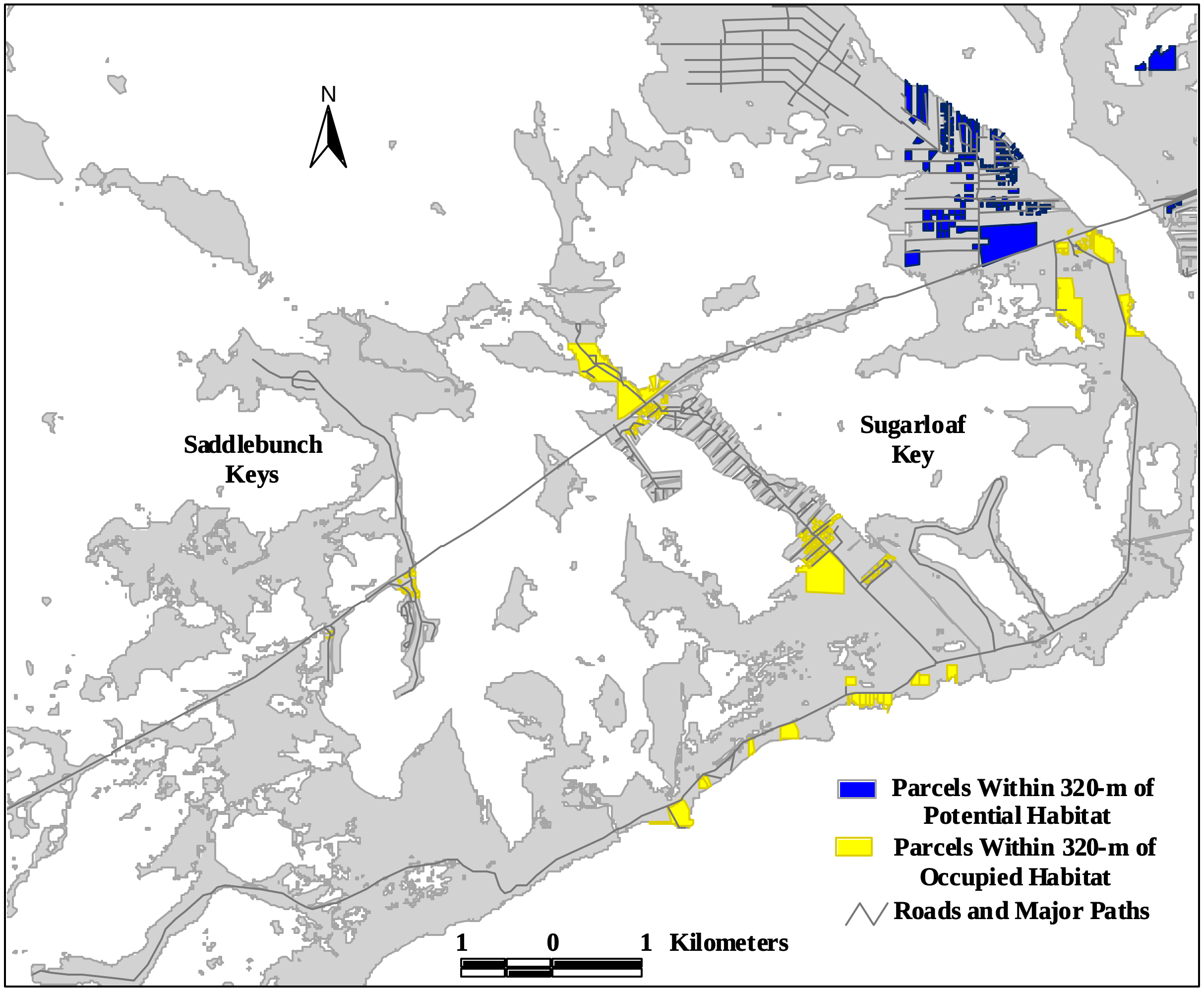

Fig. 4.27. Parcels of land with existing human development within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Sugarloaf Key in 2001–2003. Feral or free-roaming domestic cats on these properties would be reasonably likely to enter adjacent areas of occupied or potential rabbit habitat.

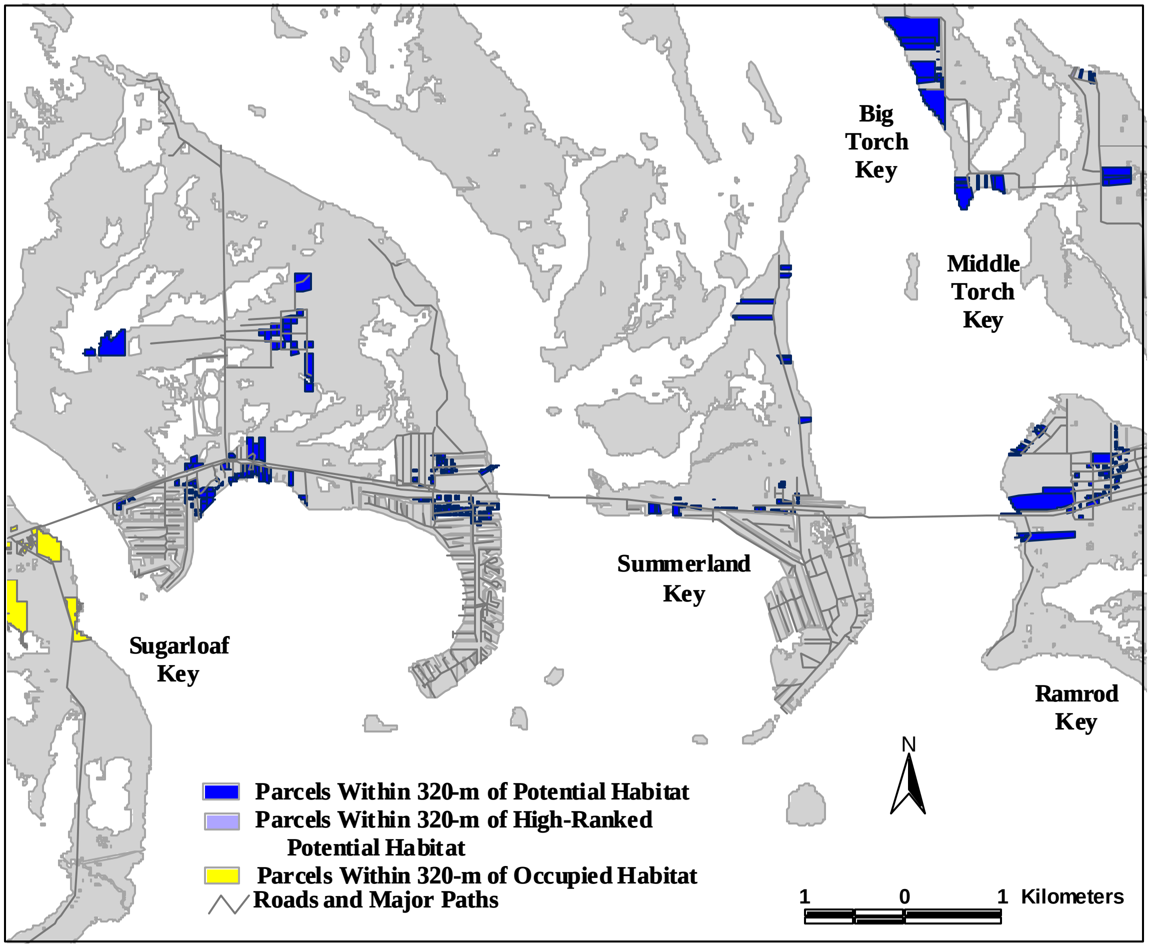

Fig. 4.28. Parcels of land with existing human development within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Cudjoe and Summerland keys and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys in 2001–2003. Feral or free-roaming domestic cats on these properties would be reasonably likely to enter adjacent areas of occupied or potential rabbit habitat. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

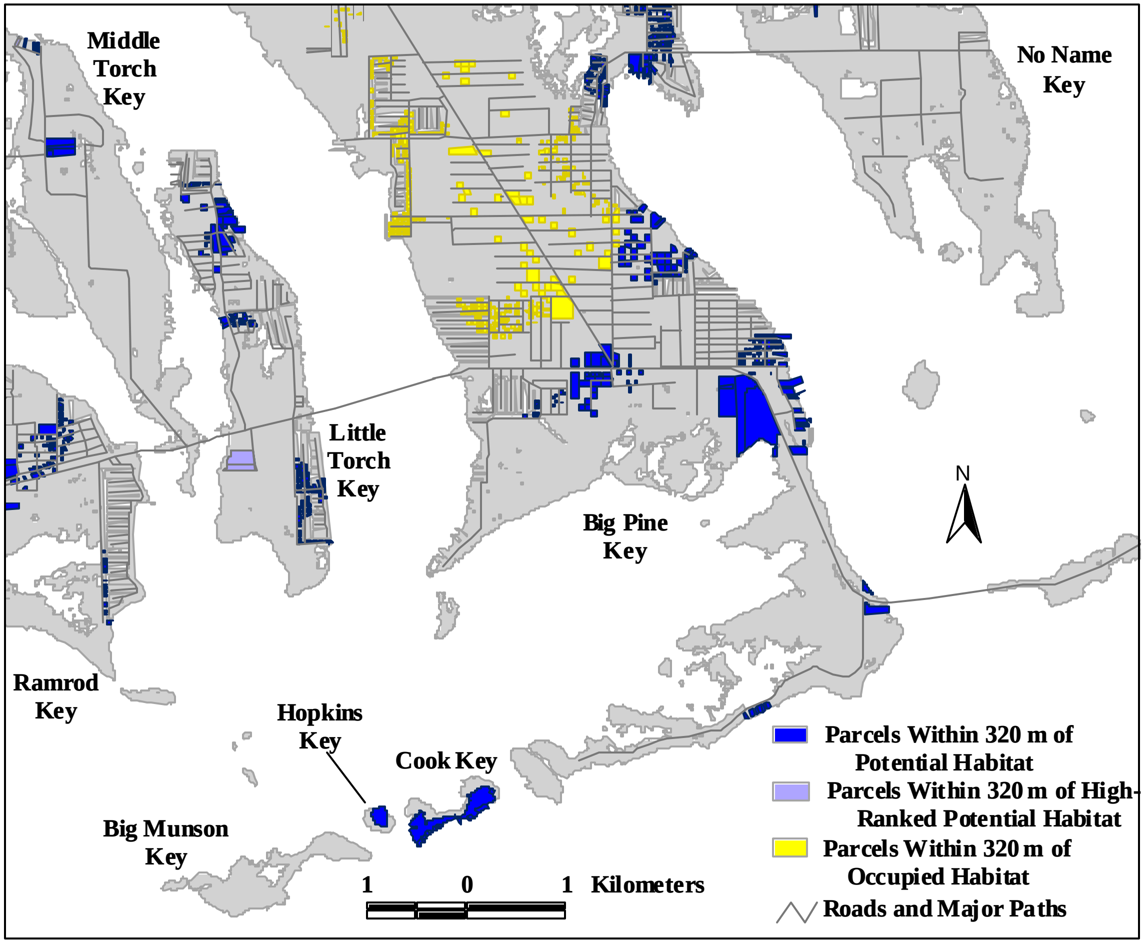

Fig. 4.29. Parcels of land with existing human development within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Little Torch, Hopkins, Cook, and No Name keys and portions of Ramrod, Big Pine, and Middle Torch keys in 2001–2003. Feral or free-roaming domestic cats on these properties would be reasonably likely to enter adjacent areas of occupied or potential rabbit habitat. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

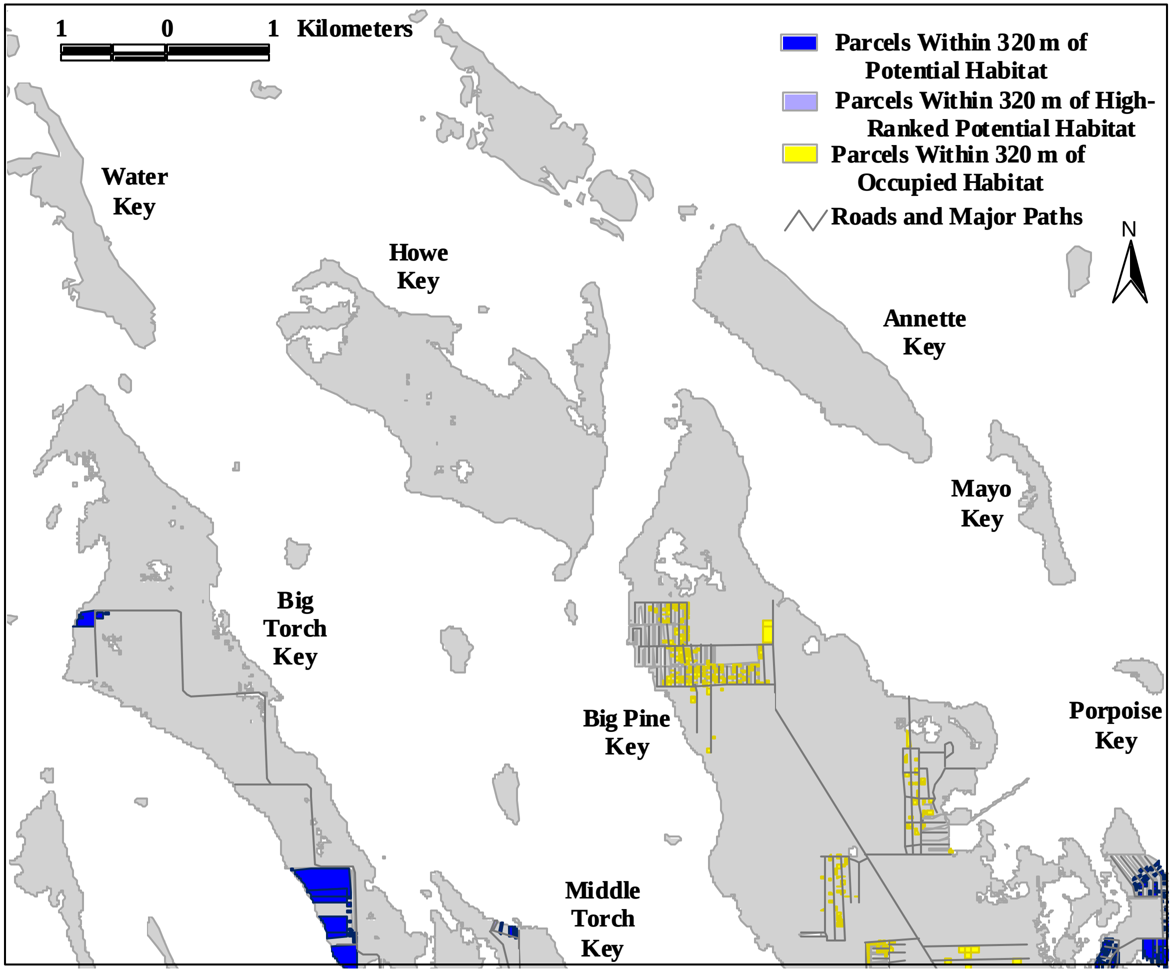

Fig. 4.30. Parcels of land with existing human development within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Big Torch Key and portions of Big Pine and Middle Torch keys in 2001–2003. Feral or free-roaming domestic cats on these properties would be reasonably likely to enter adjacent areas of occupied or potential rabbit habitat. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

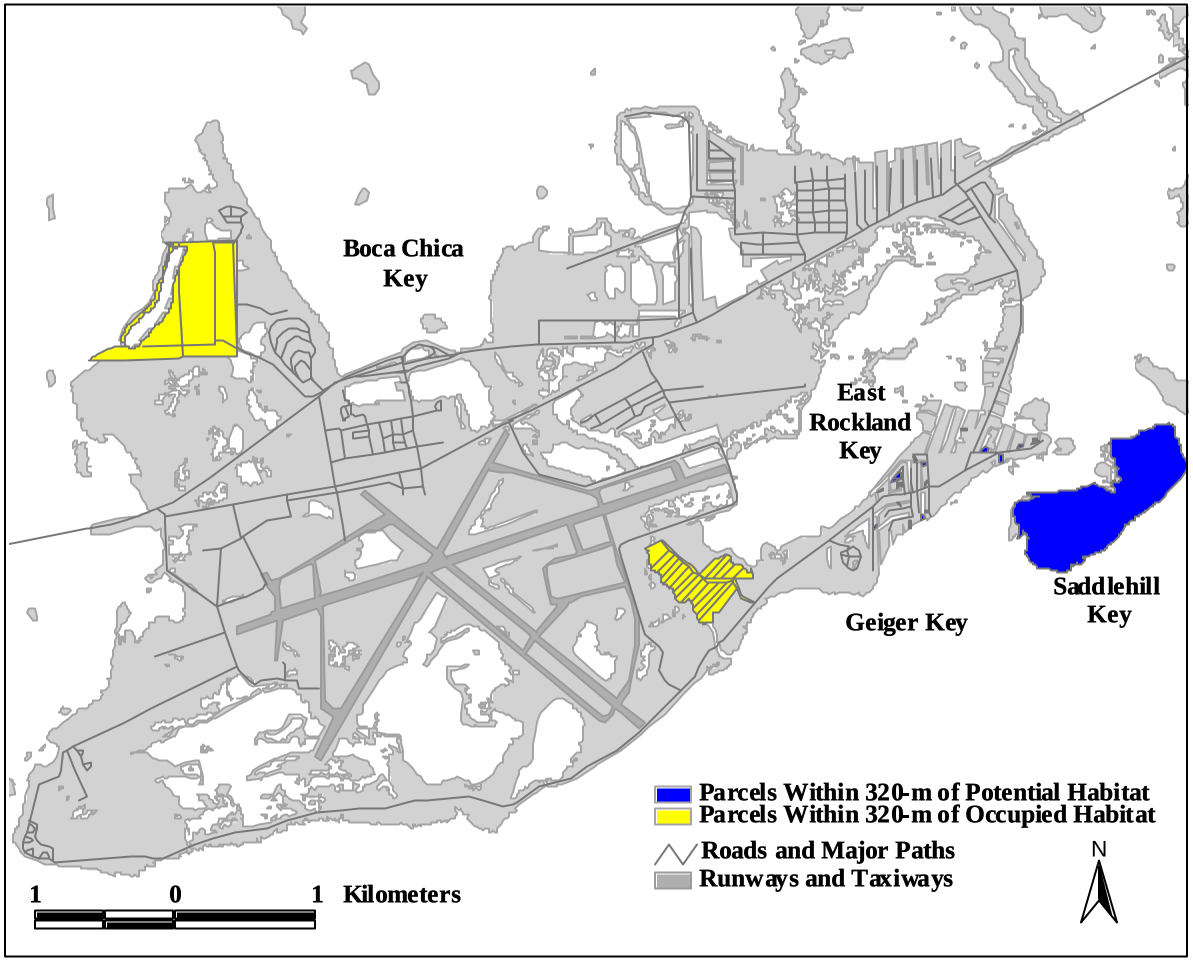

Fig. 4.31. Parcels of undeveloped, privately-owned land within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Boca Chica, East Rockland, Geiger, and Saddlehill keys in 2001–2003. If these parcels were to be developed, secondary impacts to rabbits from feral and domestic cats could result.

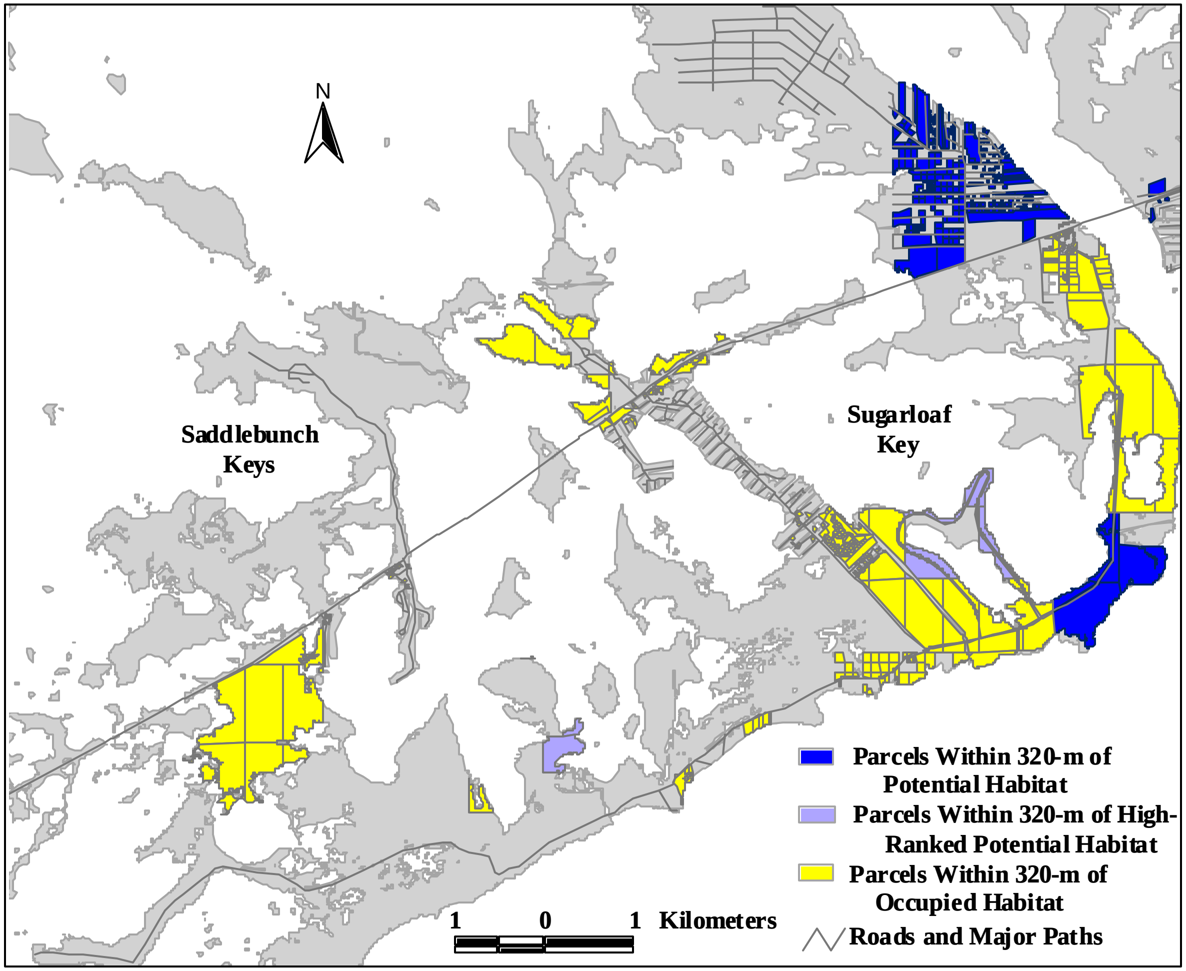

Fig. 4.32. Parcels of undeveloped, privately-owned land within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Sugarloaf and the Saddlebunch keys in 2001–2003. If these parcels were to be developed, secondary impacts to rabbits from feral and domestic cats could result. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

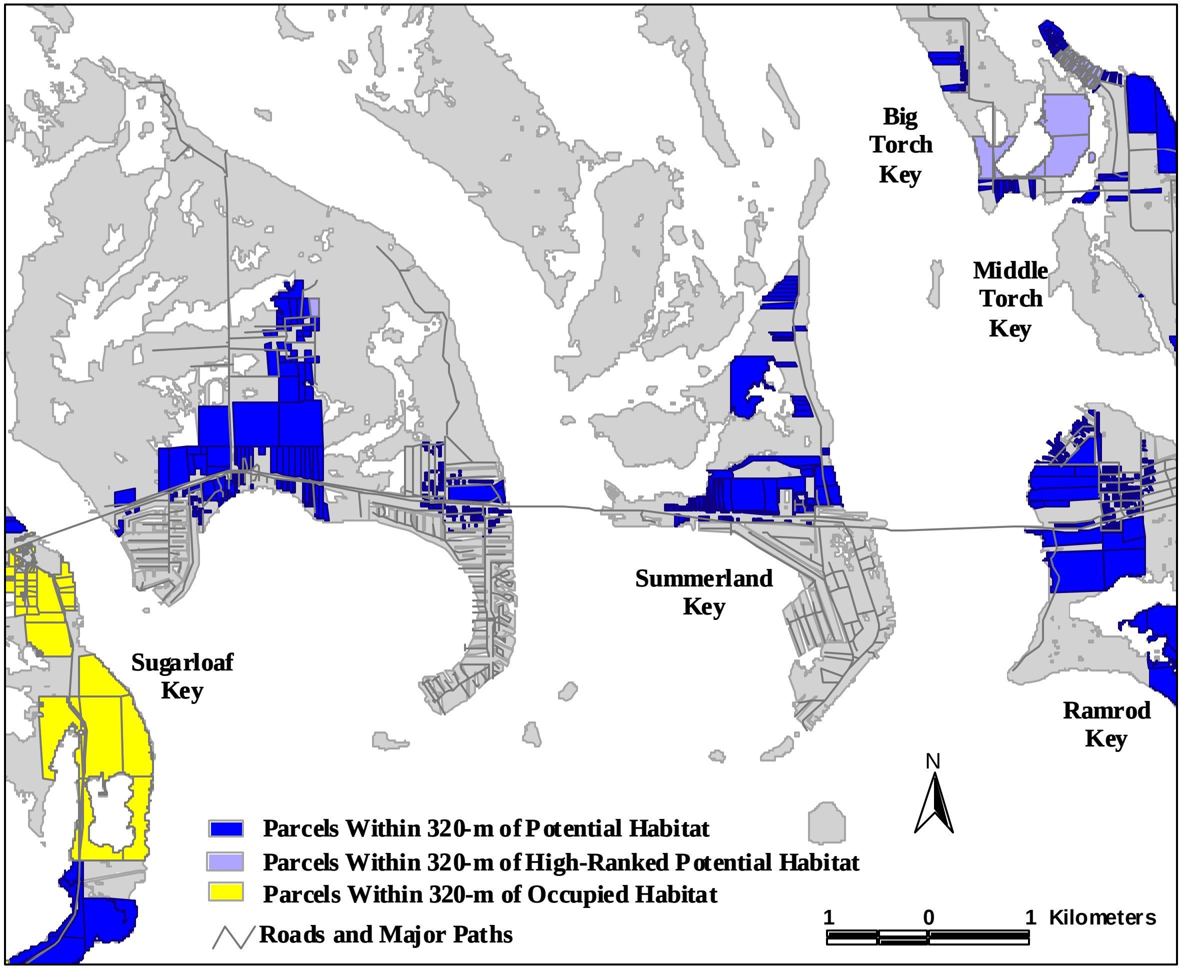

Fig. 4.33. Parcels of undeveloped, privately-owned land within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Cudjoe and Summerland keys and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys in 2001–2003. If these parcels were to be developed, secondary impacts to rabbits from feral and domestic cats could result. Potential habitat that received a high Potential Habitat Score are distinguished from other potential habitat.

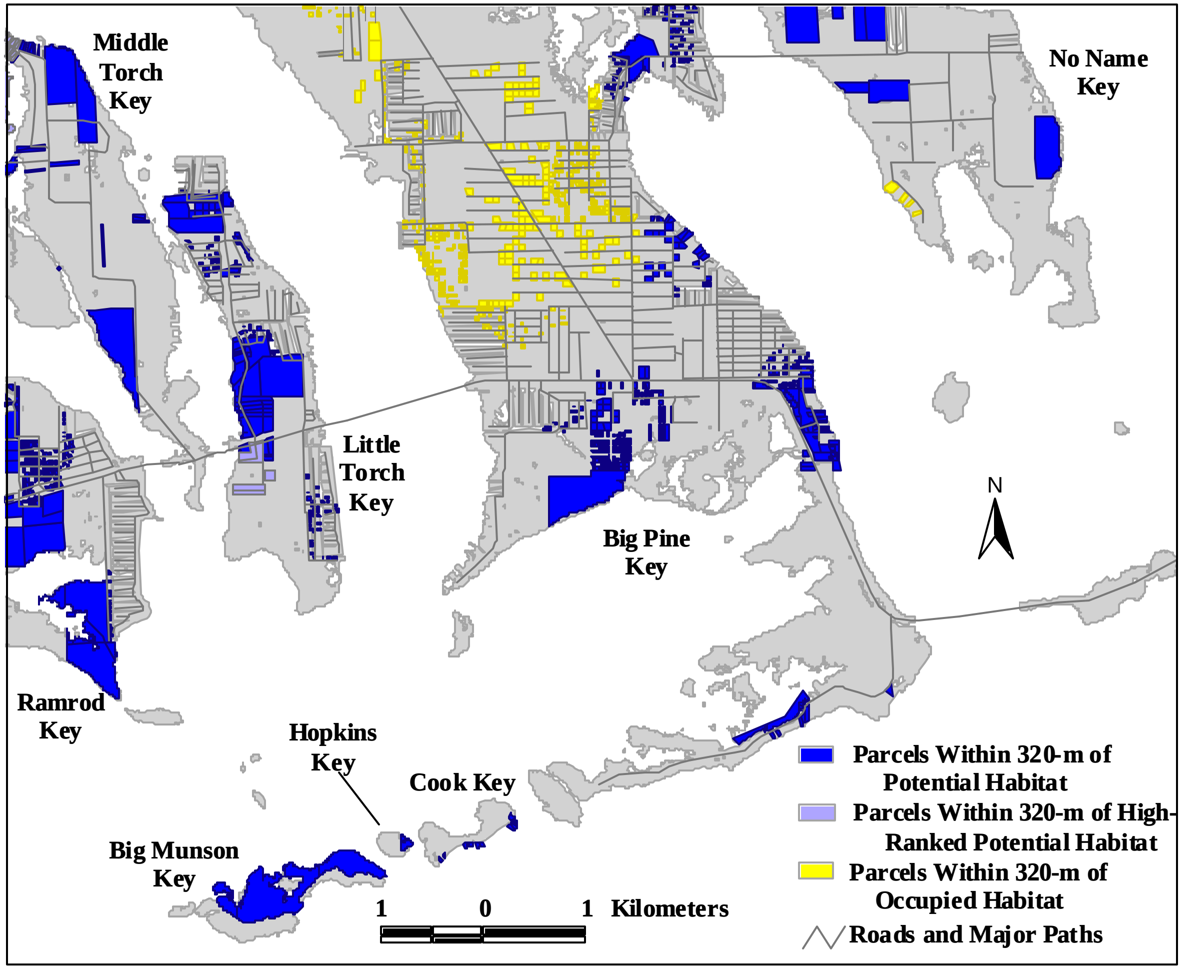

Fig. 4.34. Parcels of undeveloped, privately-owned land within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Cudjoe and Summerland keys and portions of Sugarloaf, Big Torch, Middle Torch, and Ramrod keys in 2001–2003. If these parcels were to be developed, secondary impacts to rabbits from feral and domestic cats could result. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

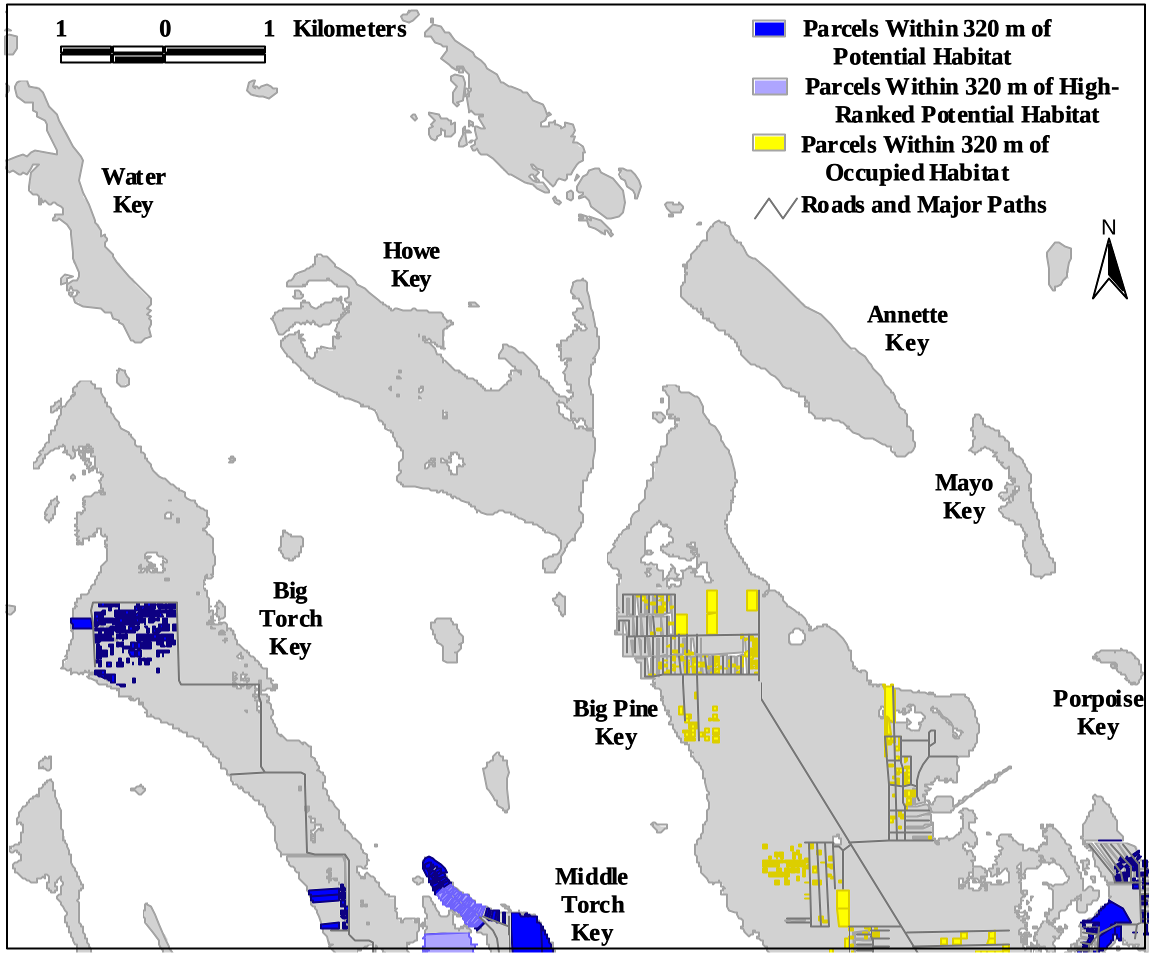

Fig. 4.35 Parcels of undeveloped, privately-owned land within 320-m of the area encompassed by occupied or potential populations of the Lower Keys marsh rabbit on Big Torch Key and portions of Middle Torch and Big Pine keys in 2001–2003. If these parcels were to be developed, secondary impacts to rabbits from feral and domestic cats could result. Potential habitat that received a high Potential Habitat Score is distinguished from other potential habitat.

Management of Cats.-- The LKMR's Recovery Plan calls for a reduction in non-native nuisance species of 80%. Control of feral and free-ranging domestic cats in the Lower Keys will require a comprehensive approach involving land-use planning, landowner education, legislation and ordinances, and cat removal. Cat colonies and trap-neuter-release programs should not be employed, as these programs are not always effective and may pose health risks to humans (Brooks 2000, Castillo 2001, Clarke and Pacin 2002). Controlling free-roaming cats is a complex and controversial issue and will require strong political will at both the local and state levels (Clarke and Pacin 2002).

First, additional human development could lead to an increase in cats due to abandonment, feeding of feral cats, or the addition of free-roaming domestic cats. Therefore, additional secondary impacts from cats can be partially ameliorated by acquiring undeveloped lots within and directly surrounding LKMR habitat. Many of these lots have already been addressed above in the sections related to land acquisition, and most lots adjacent to occupied populations have been classified as Tier 1. Within the 320-m buffer, MCDPER should consider reclassifying Tier II lots within subdivisions that are < 50% developed to Tier I to avoid potential secondary impacts. In areas where Tier III lots are within 320 m of rabbit habitat, a feral or domestic cat problem probably already exists. Undeveloped Tier III lots that are not addressed in the land-acquisition section of this chapter should be developed to promote infill, but alternative measures must be taken to ensure existing and future threats from cats are controlled.

Second, local, state, and federal government agencies charged with protecting native wildlife should support existing educational initiatives such as the Cats Indoors! program (American Bird Conservancy, Washington, D. C., USA). Moreover, the Florida Fish and Wildlife Conservation Commission (FWCC) and USFWS should provide educational materials and programs to schools and landowners concerning the impacts of feral and free-ranging domestic cats on native wildlife. Educational materials also should include human health concerns and concerns about the health and well-being of the cats themselves, as the public does not always view impacts on wildlife as a strong enough reason to control cats (Ash and Adams 2003).

Third, government bodies could use legislation and ordinances to lessen the impact of cats. For example, the exception for cats should be removed from Section 3-7(1) of the Monroe County, Florida code, which restricts owners from letting all animals except cats roam freely on private or public property. Moreover, Monroe County could enforce Section 3-16 of the Monroe County Code, which limits the number of cats that may be kept by an individual, and the county could pass an ordinance making it unlawful to feed feral cats. Existing trap-neuter-release programs could be exempted from the feeding ban if they obtain a license from the county. Monroe County should inform the public through signage or other educational materials about Section 3-7(8) of the Monroe County Code, which prohibits the abandonment of cats and other domestic animals. Abandonment of cats also is considered unlawful in

Florida under statute 828.13(3) (FWCC 2003). Cat owners should be given incentives, such as reduced license fees, to have cats spayed or neutered (FWCC 2003).

Finally, cats will need to be captured and removed from some areas. The primary responsibility for removal of feral cats throughout much of the Lower Keys belongs to Monroe County Animal Control. Objective 207.3 in the Monroe County Comprehensive Plan (Monroe County Growth Management Division 1993) stated Monroe County's commitment to controlling free-roaming domestic pets that pose a threat to native wildlife species. On Boca Chica Key, the U. S. Navy has included plans to remove feral cats as part of its Integrated Natural Resources Management Plan (Department of the Navy, Southern Division Naval Facilities Engineering Command 2002). The FWCC has pledged to control the impacts of feral and domestic cats on state conservation lands and to assist local governments to protect wildlife on public lands (FWCC 2003). A cooperative effort involving the FWCC, Monroe County, and the USFWS will likely be necessary.

Red Imported Fire Ants

Red imported fire ants have expanded their distribution in the Lower Keys over the past decade and now occupy the saltmarsh/buttonwood transition zone, hardwood hammock, and pineland as well as developed areas (Deyrup et al. 1988, Porter 1992, Forys et al. 2002). Forys et al. (2002) suggested the spread of the red imported fire ant was due at least in part to the construction of roads and other human development. Red imported fire ants are known to prey upon a variety of vertebrate species, including nestling cottontails (Hill 1969, Allen et al. 1994), but the impact on nestling LKMRs is unknown. Moreover, it is possible red imported fire ants indirectly impact the behavior and movements of adult LKMRs (Forys et al. 2002).

I noted the presence of fire ant mounds encountered in occupied and potential rabbit habitat patches during re-visits to 85 patches in May and June 2003. No attempt was made to distinguish between red imported fire ants and native southern fire ants (*S. geminata*). E. Forys (Eckerd College, personal communication) noted that southern fire ants were uncommon compared to red imported fire ants in the Lower Keys.

Fire ant mounds were discovered in 16 of 85 patches that were visited. Eleven of the 16 patches were occupied by LKMRs. Mounds were not always readily seen, and all parts of each patch were not surveyed for fire ant mounds. Therefore, it is suspected red imported fire ants are more prevalent in LKMR habitat than my surveys suggested.

Fire ant control could take the form of applying bait to mounds (e.g., Cook 2003), or, in the future, by using biological control agents (Drees and Gold 2003). However, managers should take caution to avoid eliminating remaining populations of the native southern fire ant. Managers should be aware that efforts could lead to fire ant suppression, but would be unlikely to eradicate the species (Drees and Gold 2003). Fire ant control would require a sustained effort, which could prove expensive and time consuming. Thus, it would be wise to first study the impact of red imported fire ants on native wildlife. The impact of fire ants on nestling LKMRs, for instance, could be studied using time-lapse video cameras with infrared lights (e.g., Brown et al. 1998) placed near LKMR nests.

Raccoons and Black Rats

This method also could be used to study the effects of raccoons and black rats on nestling survival. Considering LKMRs breed year-round and can produce 3–4 litters per year with 1–3 young per litter (Forys 1995), juvenile rabbits should make up a substantial proportion of the rabbits in a given habitat patch. For example, Martinson et al. (1961) reported a 4-year mean of 61% juveniles in January–February for a population of swamp rabbits (*Sylvilagus aquaticus*) in Missouri, and Hunt (1959) found that 32% of swamp rabbits collected in Texas over a 12-month period were juveniles. Juvenile eastern cottontails composed >80% of eastern cottontails harvested in the fall in Illinois, Missouri, Ohio, and Wisconsin (Edwards 1964). It should be noted, however, that these data might be biased due to differential vulnerability of juveniles to hunting (Edwards 1964). Few juvenile or subadult LKMRs were caught during trapping conducted as part of a reintroduction program (Chapter III), and juvenile pellets were encountered infrequently during the 2001–2003 distribution survey (personal observation). Juvenile rabbits may be more difficult to trap, and juvenile pellets may be simply harder to find. Moreover, environmental conditions may have resulted in poor reproduction over the years of my study. However, it also is possible that nestling and/or juvenile mortality were unusually high due to native and exotic predators. This might explain E. A. Forys's (Eckerd College, personal communication) observation that pellet density appears to have decreased over time even in consistently occupied patches.

Raccoons and black rats are both opportunistic predators that consume a wide variety of foods (Whitaker and Hamilton 1998). Although a native predator, raccoons may exist in abnormally high densities near human development (Department of the Navy, Southern Division Naval Facilities Engineering Command 2002, Prange et al. 2003). Black rats share the saltmarsh/buttonwood transition zone with the LKMR (Goodyear 1992, personal observation). I captured several black rats while trapping for LKMRs on Sugarloaf, Saddlebunch, and Little Pine keys (Chapter III). Closely related Norway rats (*Rattus norvegicus*) have been known to eat the young of the European rabbit (Imber et al. 2000). It is recommended future studies attempt to determine the impact of exotic predators and raccoons on both nestling and juvenile survival.

Domestic Rabbits

Another possible secondary impact from development is the release or escape of domestic European rabbits into the wild. Domestic rabbits may occasionally be seen adjacent to marsh rabbit habitat (personal observation). Although domestic rabbits probably do not pose a competitive threat to the LKMR due to limited numbers, it is possible they could transmit diseases. It should be noted, however, that no evidence could be found in the literature of domestic rabbits transmitting diseases to wild lagomorphs. To err on the side of caution, land managers should educate the public about the possible danger of releasing European rabbits into native environments. Moreover, pet owners should be made aware that abandonment of a domestic animal is unlawful under Section 3-7(8) of the Monroe County code.

Vehicle Mortality

Finally, additional development will be accompanied by more vehicles and possibly a greater potential of vehicle mortality for the LKMR. Vehicles caused almost one-third of LKMR mortalities observed by Forys and Humphrey (1999) on Boca Chica Key. Vehicle mortalities have been reported from Boca Chica, Saddlebunch, and Big Pine keys during my study, though road-killed rabbits were encountered rarely (A. Schuetz, Naval Air Facility Key West, personal communication; personal observation). Naval Air Facility, Key West, should maintain existing signage and mowing restrictions on Boca Chica Key, where rabbit patches generally abut roads, runways, and taxiways. Signage and speed control measures may be necessary in localized areas on other Keys if vehicle mortality "hot spots" develop. Local residents should be encouraged to report sightings of road killed rabbits to the USFWS so these areas can be identified.

PATCH RESTORATION AND ENHANCEMENT

Restoring and enhancing LKMR habitat could benefit the LKMR metapopulation in 2 ways. First, restoration and enhancement could increase the density and/or survival of rabbits in local populations, thereby decreasing the probability of local extinction. Second, restoration and enhancement could increase the number of local populations by making areas more suitable for reintroduction or natural colonization. During the distribution survey (Chapter II), I identified possible restoration needs in each patch.

Invasive exotic Plant Species

Exotic plant species were found in 90 patches (Appendix E). The most common species were Australian pine, Brazilian pepper, latherleaf, and lead tree. Patch 103 on Saddlehill Key had a thick cover of latherleaf that prevented the growth of herbaceous species and rendered much of the patch unsuitable for rabbits. Patches 19, 21, and 172 on Boca Chica Key supported large stands of lead tree that rabbits were using as cover. In other patches, invasive exotic plants were present but not dominant.

Land managers should continue to implement control measures for invasive exotic vegetation, which, if left unchecked, can render habitat unsuitable for LKMRs (Forys 1995, personal observation). The Florida Keys Wildlife Refuges and NAFKW, both support active exotics removal programs, and the Nature Conservancy partners with private landowners to control exotics. Continued, consistent efforts from these groups will be necessary to prevent the degradation of LKMR habitat. It should be noted, however, that managers must provide alternative cover before removing exotics from patches such as 19, 21, and 172 on Boca Chica Key, where rabbits are using lead tree for cover.

Hardwood Control

Portions of patch 52 on Big Pine Key were frequently burned and were thought to have been farmed prior to 1951 (Alexander and Dickson 1970). Since that time, what was once an open grass prairie has started to be replaced by shrubs and trees associated with hardwood hammocks (Alexander and Dickson 1970; N. Silvy, Texas A&M University, personal communication). Similarly, hardwoods have become more prevalent over time in patches on Little Pine Key (P. A. Frank, USFWS, personal communication). Rabbits probably use these clumps of hardwoods for cover. However, rabbits tend to seek cover in tall grasses and sedges rather than under hardwoods (Appendix A), and the continued encroachment of hardwood species could eventually render portions of the patch unsuitable for rabbits. Experimental hardwood control might enhance the habitat for LKMRs. A combination of mechanical clearing and fire could prove effective in patch 52, provided enough cover is left for form sites. Clearing with chainsaws might be the most appropriate method on Little Pine Key. Planting gulf cord grass or other thick grass species would help offset the loss of shrub and tree cover.

If hardwood removal proves successful in opening up more quality habitat for LKMRs, the technique could be applied to prevent the degradation of occupied habitat and to restore potential habitat. For example, T. Wilmers (USFWS, personal communication) reported an increase in the amount of hardwood vegetation in potential habitat patch 124, which was occupied by rabbits in previous surveys.

Trash Removal

Minor storm-blown trash was present at many of the patches, but 18 of the patches had larger amounts of trash (Appendix E). Eight of these patches were occupied by rabbits. The amount of trash varied from storm-blown rubbish (e.g., patch 110) to dumped appliances (e.g., patch 35) and abandoned vehicles (e.g., patch 73). Overall, trash covered only a minor portion of the patches and did not appear to be a source of significant degradation in any patch. Unless the situation becomes significantly worse, trash removal should be considered a low priority.

Reestablishment of Native Vegetation

Eight patches on NAFKW property had adjacent scarified or highly-disturbed areas that might be re-planted with native species (Fig. 4.36). Returning these sites to preferred native plant species of the LKMR could result in an increase of approximately 5 ha of habitat, all of which would be directly adjacent to currently occupied patches. In saltmarsh/buttonwood transition zones, a mosaic of gulf cord grass, saltmarsh fringe-rush, sea daisy, and seashore dropseed would provide high quality habitat for LKMRs. Knot grass (*Paspalum distichum*) also could be planted in low-lying areas, as LKMRs feed on this grass when it is available (personal observation). This restoration project could be accomplished through a cooperative effort between NAFKW and the USFWS. Some experimentation may be necessary, as a previous attempt at creating grassy saltmarsh in Patch 21 was not completely successful. Gulf cord grass and sea daisy were planted on a mixture of fill and organic material, with the expectation that other herbaceous species would eventually colonize the site. After 5 years, this effort produced gulf cord grass with an unusual vertical structure and failed to achieve a thick herbaceous ground cover of other species (personal observation).

Enhancement

It may be possible to enhance existing habitat by fostering additional escape cover. Gulf cord grass, often used for form sites and nesting areas by LKMRs (Forys 1995), can be found along roadsides and on small mounds of fill throughout the LKMR's range (personal observation). Gulf cord grass is readily available from several nurseries in south Florida, and the species is relatively easy to transplant and establish in a mixture of marl and organic material at elevations of 0.7–0.75 m (G. Milano, Miami-Dade Department of Environmental Resources Management, personal communication). Plantings also could be obtained from existing areas with gulf cord grass in the Lower Keys. Rabbit habitat in the saltmarsh/buttonwood transition zone could be enhanced by interspersing small mounds of earth planted with gulf cord grass throughout patches. This would be particularly useful in grassy saltmarsh and buttonwood transitional areas dominated by low-lying seashore dropseed. As noted in the section above, some experimentation may be required to produce the desired vegetation structure. Habitat enhancement could be used to increase the number of suitable reintroduction sites and to increase population densities at currently occupied sites.

POPULATION GENETICS

Although demographic processes are generally of more immediate concern, the role of genetics in extinctions should not be ignored, as inbreeding and genetic drift can lead to an increase in frequency or even the fixation of deleterious alleles in small populations (Lande 1988, Frankham 1995, Hedrick and Kalinowski 2000). Island populations generally exhibit less genetic variability than mainland populations (Frankham 1998). Moreover, inbreeding and genetic drift are expected to occur more rapidly when populations remain small over several generations (Lande 1988) and when species have a high reproductive rate. Thus, isolated Lower Keys marsh rabbit populations may be more likely to exhibit low genetic diversity and its potential deleterious effects.

Therefore, in addition to the management actions and research suggested above, future research should focus on the population genetics of the LKMR. Studying the gene flow among populations on the same key and among populations on different keys could lead to important insights concerning the connectivity of occupied populations. For example, although marsh rabbits are excellent swimmers (Tomkins 1935, Blair 1936), the distance they are willing to travel and the frequency with which they are willing to cross channels between islands is unknown. Moreover, the degree to which human development impedes dispersal is uncertain. Genetic studies could reveal possible barriers to dispersal, important dispersal corridors, or extreme cases of inbreeding within isolated populations. Inbreeding can

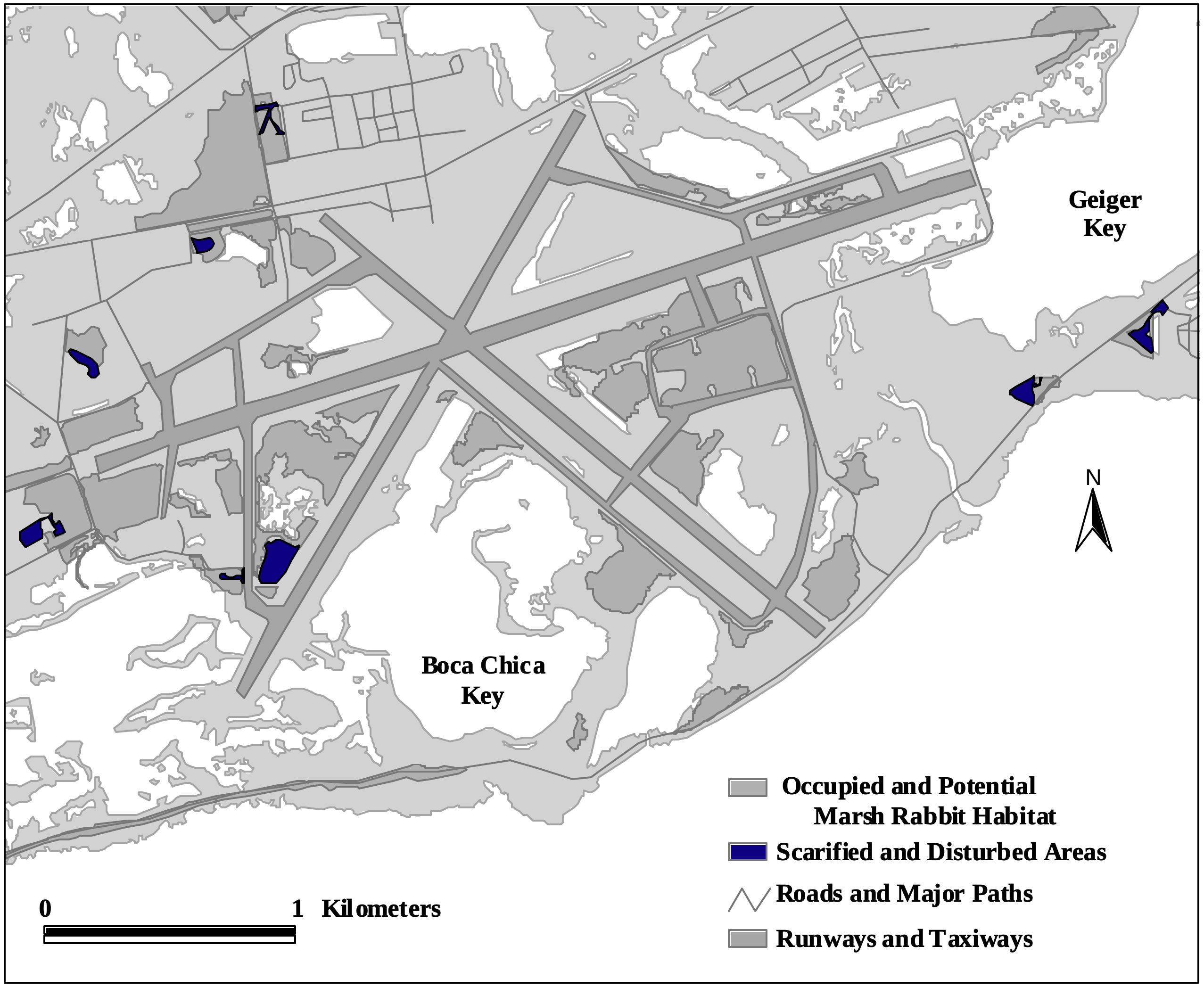

Fig. 4.36. Scarified and disturbed areas in which native vegetation could be re-established adjacent to occupied Lower Keys marsh rabbit habitat on Boca Chica and Geiger keys.

be difficult to determine in natural populations, but it may be wise to err on the side of caution (Lacy 1997, Hedrick and Kalinowski 2000). If dispersal barriers are identified or inbreeding is detected, managers could plan translocations to promote gene flow and improve the genetic health of isolated populations (Westemeier et al. 1998, Madsen et al. 1999, Mansfield and Land 2002). Individuals for these translocations could be supplied by an *in-situ*-captive-breeding program (Chapter III).

Researchers studying the population genetics of the LKMR could use techniques from other studies of lagomorph genetics. Surridge et al. (1998), for example, used microsatellites to study gene flow among populations of European rabbits. Williams et al. (2002) used microsatellite primers developed for the European rabbit to study the within and between population variability for populations of the riparian brush rabbit (*Sylvilagus bachmani riparius*). The loci used in these studies may be applicable to the LKMR as well.

CONCLUSIONS

The following list summarizes the key management actions and research projects suggested in this thesis.

Key Management Actions

1. Establishment of a long-term-monitoring protocol
2. Land acquisition
3. Reintroductions (and perhaps translocations for genetic purposes) supplied by *in-situ* captive breeding
4. Management of feral and free-roaming domestic cats
5. Control of invasive exotic plant species

Adaptive Management Programs (Combining Experimentation and Management)

1. Re-establishment of native vegetation in scarified areas
2. Habitat enhancement through provision of additional cover in both occupied and potential populations

Summary of Possible Future Research

1. Night habitat use and movements of the LKMR
2. Determining the relationship of habitat variables to LKMR demographic parameters
3. Movements and habitat use of feral and free-roaming domestic cats
4. Impacts of exotic and native predators on survival of nestling and juvenile LKMRs
5. Population genetics of the LKMR metapopulation

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APPENDIX A

RADIO TRACKING OF LOWER KEYS MARSH RABBITS

RADIO COLLARS

Thirty-six rabbits were affixed with collars bearing radio transmitters during some part of the study. Fourteen of these were translocated as part of a reintroduction program, and 14 were used as a control group during the reintroduction. The remaining rabbits were tracked outside of the time period of the reintroduction.

Collars should be between 9- and 11-cm in circumference. Researchers must ensure that collars are perfectly round, as LKMRs have slender feet that may get caught in the collar. Rabbits tend to hold their neck close to the body. When affixing the collar, gently straightening the rabbit's neck will ensure the collar fits properly. If the collar material is too wide, minor abrasions can occur on the rabbit's skin at the anterior end of the collar. Collars made from Safe-Ty Low Profile Ties (Thomas & Betts, Memphis, Tennessee, USA) were round, light-weight, and easy to affix to animals (the rabbits' hair often got in the way of nut/bolt systems). A drop of strong adhesive prevented the cable tie from tightening further. Shrink tubing was used to soften the edges of the cable ties.

FLIGHT DISTANCE

Rabbits often could be approached to within 1–3 m before flushing. Flushed rabbits rarely traveled far, especially if thick gulf cord grass was present. Two LKMRs from a freshwater wetland on Big Pine Key provided an exception to these 2 observations. These rabbits would often slink quietly away before an observer could find their form sites.

FORM SITES

The short flight distance of the LKMR allowed the determination of form sites of tracked rabbits. For 17 non-translocated rabbits with $\geq$15 locations, the form site (within 1 m^2) was found in 781 of 873 attempts. Tracked rabbits usually chose to seek cover under herbaceous or low halophytic shrub vegetation rather than under trees. Rabbits used only herbaceous or low halophytic shrub vegetation as cover for 409 form sites (52%), and used a combination of tree and herbaceous/low shrub cover for 279 locations (35%). Herbaceous and shrub species that provided the dominant cover in $\geq$10% of any rabbit's form sites included glasswort, gulf cord grass, marsh hay cord grass, salt grass, saltmarsh fringe rush, saltwort, saw grass, and sea daisy.

Some control group LKMRs hid solely under trees (13% of form sites); the tree species included black bead, black mangrove, black torch, Brazilian pepper, buttonwood, red mangrove, sea grape, Spanish bayonet (*Yucca aloifolia*), and white mangrove. Translocated rabbits on Little Pine Key occasionally hid solely under bay cedar. Translocated rabbits on Big Torch Key occasionally hid under wax myrtle, and a rabbit was seen under blolly and myrsine on 1 occasion.

Form sites of rabbits in saltwater wetlands were usually found in grassy saltmarsh, buttonwood transitional habitat, and mangrove vegetation types. In population 122 on Big Pine Key, 2 LKMRs often sought cover in small patches of freshwater hardwoods surrounded by freshwater marsh. Seventeen non-translocated rabbits used uplands (hammock and pineland) for <1% of form sites.

Two adult males in habitat patch 9 on Boca Chica Key used the mangrove vegetation type for 54% and 46% of form sites, respectively. Although the data were insufficient for strong conclusions, the use of mangroves by these 2 rabbits appeared to be seasonal. From December through April (the dry season), the rabbits used mangroves in 32 of 60 and 32 of 59 locations, respectively. In May and June, the first rabbit used mangroves in only 5 of 16 form sites. The other rabbit used mangroves for 6 of 24 form sites from May through September. This is consistent with Layne's (1974) observation of marsh rabbits congregating on higher ground during flooding and suggests that the presence of adjacent dry ground may limit the distribution of LKMRs in the mangrove vegetation type.

MOVEMENTS

Three adult rabbits on Boca Chica Key and 1 adult in the Saddlebunch Keys crossed 2-lane paved roads to visit adjacent core habitat patches. One subadult male rabbit on Boca Chica Key regularly crossed back and forth between core habitat patches 8 and 9. This is contrary to the observations of Forys (1995), which suggested LKMRs did not cross roads to visit adjacent patches.

APPENDIX B

LOWER KEYS MARSH RABBIT DISTRIBUTION SURVEY

Table B.1. Patches of Lower Keys marsh rabbit habitat included in the 2001–2003 range-wide distribution survey in the Lower Keys of Florida, USA. The patches have been grouped into possible local populations. The ownership status of each patch is presented. "Mixed" ownership indicates a combination of privately-owned and publicly-owned parcels of land. "TNC" is the Nature Conservancy; "NAFKW" refers to Naval Air Facility, Key West; and USFWS stands for the U.S. Fish and Wildlife Service. A patch was considered to be "occupied" if fecal pellets were discovered at least once during the course of the study. "Former Name" refers to designations given to patches in surveys conducted from 1988–1995. The occupancy status in the 1988–1995 surveys also is presented.

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
1	1	East Rockland	NAFKW	Occupied	2.6	2	2	1	Occupied
2	1	East Rockland	NAFKW	Occupied	0.9	2	1	2	Occupied
3	3	Boca Chica	NAFKW	Occupied	1.7	1	1	3	Occupied
4	4	Boca Chica	NAFKW	Potential	1.7	3	0	4	Occupied
5	5	Geiger	NAFKW	Occupied	1.1	2	1	5	Occupied
6	6	Boca Chica	NAFKW	Occupied	0.5	2	1	6	Potential
7	7	Boca Chica	NAFKW	Occupied	1.6	2	1	7	Occupied
8	8	Boca Chica	NAFKW	Occupied	4.3	3	3	8	Occupied
9	8	Boca Chica	NAFKW	Occupied	6.3	3	3	9	Occupied
10	10	Geiger	NAFKW	Occupied	0.4	2	2	10	Occupied
11	11	Geiger	NAFKW	Potential	1.0	2	0	11	Occupied
12	8	Boca Chica	NAFKW	Occupied	1.3	2	2	12	Occupied
13	11	Geiger	NAFKW	Potential	3.7	2	0	13	Occupied
14	14	Boca Chica	NAFKW	Occupied	1.4	2	2	14	Occupied
15	15	Boca Chica	NAFKW	Occupied	2.5	2	2	15	Occupied
16	8	Boca Chica	NAFKW	Occupied	1.3	2	2	16	Occupied
17	17	Boca Chica	NAFKW	Potential	1.0	2	0	17	Occupied
18	18	Boca Chica	NAFKW	Occupied	4.4	2	2	18	Occupied
19	19	Boca Chica	NAFKW	Occupied	11.3	3	3	19	Occupied
20	19	Boca Chica	NAFKW	Occupied	4.1	2	2	20	Occupied

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
21	19	Boca Chica	NAFKW	Occupied	9.6	3	3	21	Occupied
22	22	Boca Chica	NAFKW	Occupied	1.4	2	1	22	Occupied
23	8	Boca Chica	NAFKW	Occupied	10.9	3	3	23	Occupied
24	8	Boca Chica	NAFKW	Occupied	2.0	3	2	24	Occupied
25	25	Boca Chica	Private	Occupied	1.7	1	1	25	Occupied
26	26	Boca Chica	NAFKW	Occupied	5.1	2	2	26	Occupied
28	28	Saddlebunch	USFWS	Potential	0.1	2	0	28	Occupied
29	29	Saddlebunch	NAFKW	Occupied	4.4	3	3	29	Occupied
30	30	Saddlebunch	NAFKW	Occupied	1.8	1	1	30	Occupied
31	31	Sugarloaf	Private	Occupied	5.0	1	1	31	Occupied
32	32	Sugarloaf	Private	Occupied	10.0	1	1	32	Occupied
33	33	Sugarloaf	Mixed	Occupied	21.5	3	3	33	Occupied
34	34	Sugarloaf	Private	Occupied	8.4	2	2	34	Occupied
35	35	Sugarloaf	Private	Occupied	2.3	2	1	35	Occupied
36	36	Sugarloaf	Private	Potential	10.6	1	0	36	Potential
37	37	Upper Sugarloaf	Private	Potential	4.2	1	0	37	Potential
38	37	Upper Sugarloaf	Private	Potential	6.3	1	0	38	Potential
39	39	Upper Sugarloaf	Mixed	Potential	3.2	1	0	39	Potential
40	40	Upper Sugarloaf	Private	Potential	1.2	1	0	40	Potential
41	41	Cudjoe	Private	Potential	3.2	2	0	41	Potential
42	42	Cudjoe	USFWS	Potential	5.4	2	0	42	Potential
43	43	Cudjoe	Private	Potential	2.6	1	0	43	Potential
44	44	Summerland	Mixed	Potential	1.8	1	0	44	Potential
45	45	Ramrod	Private	Potential	3.0	2	0	45	Potential
46	46	Middle Torch	USFWS&State	Potential	3.7	1	0	46	Potential
47	47	Middle Torch	Private	Potential	4.8	1	0	47	Potential
48	48	Big Torch	Mixed	Potential	4.1	1	0	48	Potential
49	49	Big Torch	Mixed	Potential	14.6	1	0	49	Potential
50	50	Big Torch	Mixed	Potential	1.1	1	0	50	Potential
51	51	Little Torch	TNC	Potential	5.4	1	0	51	Potential

Table B.1 (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
52	52	Big Pine	USFWS&State	Occupied	51.2	3	3	52	Occupied
53	53	Big Pine	Mixed	Occupied	44.0	3	3	53	Occupied
54	54	Big Pine	SFWMD	Occupied	11.9	2	2	54	Occupied
55	54	Big Pine	Mixed	Occupied	5.4	2	2	55	Occupied
56	56	Big Pine	Private	Potential	1.3	1	0	56	Occupied
57	57	Big Pine	Private	Potential	0.3	2	0	57	Occupied
58	58	Big Pine	USFWS	Potential	1.2	2	0	58	Occupied
59	59	No Name	USFWS	Potential	1.7	1	0	59	Potential
60	60	Boca Chica	NAFKW	Potential	5.8	1	0	N1	Potential
61	61	Sugarloaf	Private	Occupied	5.1	1	1	N10	Potential
62	62	Sugarloaf	State	Occupied	2.6	2	1	N11	Potential
63	63	Sugarloaf	State	Potential	1.8	1	0	N12	Potential
64	64	Saddlebunch	State	Potential	3.0	1	0	N13	Potential
65	65	Upper Sugarloaf	Mixed	Potential	0.7	1	0	N14	Potential
66	66	Upper Sugarloaf	USFWS	Potential	1.5	1	0	N15	Potential
67	67	Cudjoe	County&USFWS	Potential	5.3	2	0	N16	Potential
68	68	Cudjoe	USFWS	Potential	1.7	2	0	N17	Potential
69	69	Cudjoe	USFWS	Potential	1.0	2	0	N18	Potential
70	70	Summerland	County	Potential	2.1	2	0	N19	Potential
71	71	Boca Chica	NAFKW	Potential	1.0	1	0	N2	Potential
72	70	Summerland	Mixed	Potential	6.1	2	0	N20	Potential
73	70	Summerland	Mixed	Potential	3.3	2	0	N21	Potential
74	70	Summerland	Mixed	Potential	8.1	2	0	N22	Potential
75	75	Ramrod	Private	Not Surveyed	0.4	N/A	N/A	N23	Potential
76	76	Ramrod	Private	Potential	2.0	1	0	N24	Potential
77	77	Ramrod	Private	Not Surveyed	3.3	N/A	N/A	N25	Potential
78	78	Big Torch	Private	Not Surveyed	2.7	N/A	N/A	N26	Potential
79	49	Big Torch	USFWS	Potential	5.3	1	0	N27	Potential
80	49	Big Torch	Mixed	Potential	2.3	1	0	N28	Potential
81	81	Big Torch	USFWS	Potential	1.2	1	0	N29	Potential

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
82		Boca Chica	NAFKW	Potential	2.1	1	0	N3	Potential
83		Big Torch	Private	Potential	0.8	1	0	N30	Potential
84	84	Big Torch	Mixed	Potential	7.5	1	0	N31	Potential
85	54	Big Pine	TNC&State	Occupied	0.7	2	1	N32	Potential
86	54	Big Pine	Mixed	Occupied	15.8	2	2	N33	Potential
87	52	Big Pine	USFWS	Potential	4.4	2	0	N34	Potential
88	88	Big Pine	Mixed	Occupied	6.7	2	2	N35	Potential
89	58	Big Pine	Mixed	Potential	5.8	2	0	N36	Potential
90	54	Big Pine	Mixed	Occupied	4.6	2	2	N37	Potential
91	91	Snipe Point	USFWS	Not Surveyed	2.1	N/A	N/A	N38	Potential
92	92	Big Johnson	USFWS	Potential	1.3	1	0	N39	Potential
93	93	Boca Chica	NAFKW	Occupied	5.9	3	3	N4	Potential
94	94	Big Johnson	USFWS	Potential	2.5	1	0	N40	Potential
95	95	No Name	USFWS	Occupied	1.7	2	1	N41	Potential
96		Little Johnson	State	Potential	1.5	1	0	N42	Potential
97	97	Mud	USFWS	Not Surveyed	0.8	N/A	N/A	N43	Potential
98	98	Marvin	USFWS	Not Surveyed	0.7	N/A	N/A	N44	Potential
99	99	Little Pine	USFWS	Reintroduced	10.5	1	0	N45	Potential
100	100	Hopkins	Private	Not Surveyed	1.0	N/A	N/A	N46	Potential
101	101	Cook	Private	Not Surveyed	2.4	N/A	N/A	N47	Potential
102	102	Boca Chica	NAFKW	Occupied	2.8	2	2	N48	Occupied
103	103	Saddlehill	Private	Potential	2.4	1	0	N49	Occupied
104	104	Big Pine	USFWS	Potential	1.1	2	0	H15	Occupied
105	105	Saddlebunch	USFWS	Occupied	2.4	2	2	N50	Occupied
106	106	Saddlebunch	Mixed	Occupied	9.3	2	2	N52	Occupied
107	107	Saddlebunch	USFWS	Occupied	0.4	2	2	N53	Occupied
108	108	Saddlebunch	Private	Occupied	3.5	2	2	N54a	Occupied
109	109	Sugarloaf	Private	Potential	1.1	1	0	N55	Occupied
110	110	Big Munson	Private	Potential	9.8	1	0	N56	Occupied
111	54	Big Pine	Mixed	Occupied	14.8	2	2	P111	Occupied

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
112	112	Big Pine	USFWS	Potential	1.8	2	0	N58	Occupied
113		Big Pine	Private	Potential	0.8	1	0	N59	Occupied
114	114	Saddlebunch	USFWS	Potential	0.4	2	0	N6	Potential
115	54	Big Pine	Mixed	Occupied	6.7	2	2	N61	Occupied
116	88	Big Pine	USFWS	Occupied	3.8	2	2	P116	Unknown
117	54	Big Pine	Mixed	Occupied	7.4	2	2	N62	Occupied
118	118	Mayo	USFWS	Occupied	4.4	1	1	N63	Occupied
119	118	Mayo	USFWS	Occupied	4.9	2	2	N64	Occupied
120	120	Porpoise	USFWS	Potential	2.4	2	0	N65	Occupied
121	121	Annette	USFWS	Occupied	23.6	1	1	N66	Occupied
122	122	Big Pine	Mixed	Occupied	34.5	3	3	N60	Occupied
123	62	Sugarloaf	State	Occupied	2.7	2	1	N7a	Potential
124	57	Big Pine	Private	Potential	4.2	2	0	P124	Occupied
125	125	Sugarloaf	State	Potential	1.8	1	0	N8	Potential
126	126	Sugarloaf	Private	Occupied	6.7	1	1	P126	Potential
127	127	Big Pine	Mixed	Potential	2.2	2	0	P127	Unknown
128	128	Saddlebunch	USFWS	Potential	1.2	2	0	P128	Unknown
129	129	Water	USFWS	Potential	1.9	1	0	P129	Potential
130	130	Big Pine	Mixed	Potential	2.3	2	0	P130	Occupied
131		Big Pine	Mixed	Potential	1.0	2	0	P131	Occupied
132	52	Big Pine	USFWS	Occupied	19.7	2	2	P132	Unknown
133	52	Big Pine	USFWS	Occupied	0.7	2	2	P133	Unknown
134	134	Big Pine	USFWS	Occupied	4.3	2	2	P134	Unknown
135	52	Big Pine	USFWS	Occupied	0.5	2	2	P135	Unknown
136	136	Big Pine	USFWS	Occupied	0.2	2	2	P136	Unknown
137	137	Big Pine	USFWS	Occupied	0.1	1	1	P137	Unknown
138	137	Big Pine	USFWS	Occupied	5.0	2	2	P138	Unknown
139	53	Big Pine	USFWS	Occupied	0.4	2	2	P139	Unknown
140	52	Big Pine	USFWS	Occupied	1.3	2	1	P140	Unknown
141	122	Big Pine	USFWS	Occupied	0.2	1	1	P141	Unknown

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
142	142	Little Pine	USFWS	Reintroduced	0.4	1	0	P142	Unknown
143	143	Big Pine	USFWS	Occupied	0.1	2	2	P143	Unknown
144	144	Saddlebunch	USFWS	Occupied	0.3	2	1	N51a	Occupied
145	41	Cudjoe	Private	Potential	1.1	1	0	P145	Unknown
146	42	Cudjoe	USFWS	Potential	2.3	1	0	P146	Unknown
147	147	Cudjoe	USFWS	Potential	0.7	1	0	P147	Unknown
148	54	Big Pine	Mixed	Occupied	4.2	2	2	P148	Unknown
149	144	Saddlebunch	USFWS	Potential	0.1	2	0	N51b	Occupied
150	150	Water	USFWS	Potential	1.7	1	0	P150	Potential
151	62	Sugarloaf	State	Occupied	1.8	2	1	N7b	Potential
152	3	Boca Chica	NAFKW	Occupied	12.8	3	3	K3	Occupied
153	8	Boca Chica	NAFKW	Occupied	0.3	2	2	P153	Unknown
154	154	Big Torch	State	Potential	1.0	1	0	P154	Unknown
155	3	Boca Chica	NAFKW	Occupied	1.1	2	2	P155	Unknown
156	3	Boca Chica	NAFKW	Potential	1.2	2	0	K25	Occupied
157	3	Boca Chica	NAFKW	Occupied	1.9	2	2	P157	Unknown
158	54	Big Pine	State	Occupied	0.8	2	2	P158	Unknown
159	159	Little Pine	USFWS	Reintroduced	1.5	1	0	P159	Unknown
160	22	Boca Chica	NAFKW	Occupied	2.8	2	2	P160	Unknown
161	3	Boca Chica	NAFKW	Occupied	0.3	2	2	P161	Unknown
162	162	Saddlebunch	NAFKW	Occupied	1.3	2	2	P162	Unknown
163	163	Little Johnson	USFWS&State	Potential	5.1	1	0	P163	Unknown
164	164	East Water	USFWS	Potential	0.9	1	0	P164	Unknown
165	165	Howe	USFWS	Occupied	15.6	1	1	P165	Unknown
166	166	Howe	USFWS	Occupied	3.6	1	1	P166	Unknown
167	167	Big Torch	USFWS	Potential	3.7	1	0	P167	Unknown
168	168	Big Pine	USFWS	Potential	3.0	1	0	P168	Unknown
169	169	Boca Chica	NAFKW	Occupied	0.7	2	2	K25	Occupied
170	170	Boca Chica	NAFKW	Occupied	0.9	2	2	P170	Unknown
171	171	Boca Chica	NAFKW	Occupied	1.4	2	2	P171	Unknown

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
172	19	Boca Chica	NAFKW	Occupied	1.7	1	1	P172	Unknown
173	8	Boca Chica	NAFKW	Occupied	3.7	2	2	P173	Unknown
174	3	Boca Chica	NAFKW	Occupied	2.4	1	1	P174	Unknown
175	8	Boca Chica	NAFKW	Occupied	0.5	1	1	P175	Unknown
176	15	Boca Chica	NAFKW	Occupied	0.2	2	2	P176	Unknown
177	8	Boca Chica	NAFKW	Occupied	0.3	2	1	P177	Unknown
178	8	Boca Chica	NAFKW	Occupied	0.7	2	2	P178	Unknown
179	179	Little Torch	Private	Potential	5.1	1	0	P179	Unknown
180	46	Middle Torch	State	Potential	0.7	1	0	P180	Potential
181	181	Little Torch	TNC	Potential	3.6	1	0	P181	Unknown
182	181	Little Torch	TNC	Potential	0.7	1	0	P182	Unknown
183	49	Big Torch	Mixed	Potential	0.5	1	0	P183	Unknown
184	184	Summerland	Private	Potential	0.4	1	0	P184	Unknown
185	185	Little Torch	Mixed	Potential	1.4	1	0	P185	Unknown
186	186	Middle Torch	USFWS	Potential	0.6	1	0	P186	Unknown
187	39	Upper Sugarloaf	County	Potential	0.2	1	0	P187	Unknown
188	188	Big Torch	USFWS	Potential	5.4	1	0	P188	Unknown
189	189	Big Pine	Mixed	Potential	6.8	2	0	P189	Unknown
190	57	Big Pine	Private	Potential	1.1	2	0	P190	Unknown
191	191	Sugarloaf	Private	Occupied	1.1	2	2	P191	Unknown
192	191	Sugarloaf	Mixed	Occupied	0.2	2	2	P192	Unknown
193	193	Sugarloaf	State	Occupied	2.1	1	1	P193	Occupied
194	194	Sugarloaf	State	Occupied	4.0	1	1	P194	Occupied
195	51	Little Torch	TNC	Potential	0.4	1	0	P195	Unknown
196	196	Saddlebunch	USFWS	Occupied	0.4	2	2	P196	Unknown
197	197	Saddlebunch	USFWS	Occupied	0.7	2	2	P197	Unknown
198	39	Upper Sugarloaf	County	Potential	1.0	1	0	P198	Unknown
199	199	Saddlebunch	State	Potential	0.6	1	0	P199	Unknown
200	200	Saddlebunch	USFWS	Potential	0.4	2	0	P200	Unknown
201	201	Saddlebunch	USFWS	Potential	1.2	2	0	P201	Unknown

Table B.1. (continued)

Patch	Local population	Key	Ownership	Occupancy status	Area (ha)	Times surveyed	Times occupied	Former name	Previous surveys
202	202	Saddlebunch	USFWS	Occupied	0.6	2	1	P202	Unknown
203	56	Big Pine	USFWS	Potential	2.1	1	0	P203	Unknown
204	29	Saddlebunch	NAFKW	Occupied	4.2	3	3	P204	Unknown
205	29	Saddlebunch	NAFKW	Occupied	0.4	3	3	P205	Unknown
206	162	Saddlebunch	NAFKW	Occupied	0.7	1	1	P206	Unknown
207	31	Sugarloaf	Private	Occupied	0.3	1	1	P207	Unknown
208	40	Upper Sugarloaf	County	Potential	0.1	1	0	P208	Potential
209	209	Cudjoe	Private	Potential	0.6	1	0	H1	Potential
210	211	Geiger	NAFKW	Potential	0.2	1	0	P210	Unknown
211	10	Geiger	NAFKW	Potential	0.1	2	0	P211	Unknown
212	212	Little Pine	USFWS	Potential	0.7	1	0	P212	Unknown
213	213	Water	USFWS	Potential	0.7	1	0	P213	Potential
214	214	Cudjoe	USFWS	Potential	0.5	1	0	P214	Unknown
215	214	Cudjoe	USFWS	Potential	0.1	1	0	P215	Unknown
216	214	Cudjoe	USFWS	Potential	0.2	1	0	P216	Unknown
217	214	Cudjoe	USFWS	Potential	0.2	1	0	P217	Unknown
218	214	Cudjoe	USFWS	Potential	0.6	1	0	P218	Unknown
219	214	Cudjoe	USFWS	Potential	0.7	1	0	P219	Unknown
220	214	Cudjoe	USFWS	Potential	0.3	1	0	P220	Unknown
221	221	Cudjoe	USFWS	Potential	0.7	1	0	P221	Unknown
222	222	Cudjoe	USFWS	Potential	0.9	1	0	P222	Unknown
223	222	Cudjoe	USFWS	Potential	0.4	1	0	P223	Unknown
224	224	Cudjoe	Mixed	Potential	2.6	1	0	P224	Unknown
225	225	Cudjoe	USFWS	Potential	0.4	1	0	P225	Unknown
226	225	Cudjoe	USFWS	Potential	0.6	1	0	P226	Unknown
227	225	Cudjoe	USFWS	Potential	0.5	1	0	P227	Unknown
228	228	Saddlebunch	Private	Occupied	2.7	1	1	N54b	Occupied
229	229	No Name	USFWS	Potential	1.9	2	0	P229	Occupied

Table B.2. Description of patches of Lower Keys marsh rabbit habitat surveyed from 2001–2003 in the Lower Keys of Florida, USA.

Patch	Description
1	Mosaic of buttonwoods, mangroves, and grassy saltmarsh; intertidal marsh to N, hammock S
2	Narrow buttonwood transition zone adjacent to hammock
3	Freshwater hardwoods w/ mangrove spp. and buttonwoods w/ *Eleocharis*/*Cladium*/*Fimbristylis*
4	Buttonwoods w/ *Sporobolus* understory & some *Borrichia*; open marsh area w/ a few buttonwoods, grasses
5	*Spartina spartinae* and *patens* and narrow buttonwoods strips
6	Buttonwoods with understory of *Batis* and *Borrichia*; small patches of *Sporobolus*
7	Freshwater marsh and freshwater hardwoods; some disturbed areas to south
8	A mosaic of thick buttonwoods, intertidal marsh, and *Spartina*; also some mangroves along a ditch
9	Mosaic of low marsh, patches of *Borrichia*/*Sporobolus*, *Spartina* clumps, buttonwood "islands" & hammock
10	*Spartina spartinae* and *Spartina patens* dominate the patch
11	Narrow strip of *Spartina spartinae*, *Borrichia frutescens* and some buttonwoods
12	Some areas of *Spartina* plus some intertidal marsh and buttonwoods
13	Mosaic of *Spartina patens*, buttonwoods, and intertdal marsh
14	Patches of *Borrichia frutescens* and open saltmarsh with buttonwoods to the east
15	Buttonwoods with *Sporobolus*, some intertidal marsh, and a few *Spartina* patches
16	Grassy saltmarsh with *Borrichia frutescens* and *Sporobolus*; mangroves along a ditch; some buttonwoods
17	Beach berm w/ mosaic of grasses/vines and thick trees/shrubs
18	Mosaic of grassy saltmarsh (some *Spartina*), buttonwoods, and mangroves
19	Mosaic of freshwater hardwoods, mesic grassland, *Leucaena leucocephala*, and buttonwoods
20	Grassy saltmarsh mixed in with hammock species and some mesic grasses.
21	Mix of buttonwood and grassland areas with some *Spartina*
22	Buttonwoods and mangroves with some patches of *Borrichia frutescens*
23	Strange mosaic: mostly mangroves; some open *Eleocharis* marsh; some grassy saltmarsh.
24	A mosaic of intertidal marsh, black mangrove, tall buttonwood, *Spartina*, and *Borrichia*
25	Part is freshwater hardwood; the rest appears to be in early successional stage, with hammock species.
26	Mosaic of grassy saltmarsh (*Spartina spartinae* and *Borrichia frutescens*), buttonwoods, and grassland
28	Small patch of low *Spartina* surrouned by intertidal marsh and mangroves
29	A mosaic of buttonwood, *Borrichia*, *Spartina*, & intertidal marsh with patches of hammock and mangrove
30	Buttonwoods with *Sporobolus* understory
31	Field of mostly *Spartina spartinae*
32	Extensive *Spartina spartinae* and some *S. patens*; also, mangrove patches & buttonwoods w/ *Sporobolus*

Table B.2. (continued)

Patch	Description
33	Mosaic of buttonwoods w/ *Sporobolus* and grassy saltmarsh (*Spartina spartinae* and *patens*)
34	Freshwater hardwoods in south; buttonwoods & hammock to north and east; some *Eleocharis*
35	Open *Sporobolus saltmarsh* (w/ some *Spartina spartinae* and *patens*) mixed with patches of buttonwoods
36	Buttonwood savannah (often dense) with *Sporobolus*; few *Spartina*; some areas w/ mangroves/*Distichilis*
37	Freshwater marsh w/ *Cladium*; scattered small *Conocarpus* and red mangroves
38	Freshwater marsh w/ *Cladium* and some interspersed hardwoods; floods easily.
39	Freshwater marsh with thick *Cladium* and scattered hardwoods; floods easily
40	Freshwater marsh w/thick ground cover of *Cladium* and flooded areas of *Eleocharis*
41	Patches of *Cladium* plus areas with *Spartina spartinae* to the east
42	Narrow scrubby buttonwood transition with mostly *Monanthochloe* understory
43	Buttonwood and sawgrass with mangroves along the road
44	West is open, grassy w/ *Spartina* spp.; east is hammock/buttonwood mix.
45	Mosaic of intertidal marsh and *Sporobolus* w/a patch of thick buttonwoods to the north
46	Hammock and *Conocarpus* with rocky ground, few grasses; patches of *Cladium*
47	Mostly buttonwoods w/ *Sporobolus* and *Borrichia frutescens*
48	Buttonwoods and mangroves in south, tall *Spartina spartinae* in the north
49	Freshwater hardwoods w/ open areas & areas of thicker buttonwoods; *Cladium* understory
50	Buttonwoods w/ *Distichilis*
51	Buttonwoods bordering hammock; *Sporobolus* is primary groundcover in south, *Distichilis* in north
52	Buttonwood savanna w/ *Sporobolus* and patches of hammock spp.; plus a narrow buttonwood transition
53	Freshwater marsh, freshwater hardwoods, and freshwater pine
54	Freshwater marsh (*Cladium*) w/ some freshwater hardwoods (*Conocarpus*/mangroves)
55	Odd mosaic of freshwater hardwoods and hammock
56	Buttonwoods with *Borrichia frutescens* and thick clay-like mud
57	Small patch of *Spartina spartinae*
58	Narrow buttonwood transition zone between mangroves and hammock; *Batis* and *Sporobolus* common
59	Buttonwoods w/ *Sporobolus* and a few *Spartina*
60	Old road bordered by hammock berm and mangroves/*Batis*
61	Narrow buttonwood transition with *Sporobolus*, *Distichilis*, *Fimbristylis*, and *Borrichia* understory
62	Fairly narrow buttonwood transition zone with *Sporobolus*
63	Buttonwood, joewood, and some hammock veg with *Sporobolus*; surrounded by intertidal marsh

Table B.2. (continued)

Patch	Description
64	Thin buttonwood fringe surrounding hammock; some patches of *Fimbristylis castanea*
65	*Eleocharis* marsh surrounded by hardwoods
66	Small "island" of buttonwoods and joewood w/ *Sporobolus*; also *Fimbristylis*, *Borrichia arborescens*
67	Ridge of buttonwood/*Sporobolus* with intertidal marsh on sides; some *Borrichia* & small *Spartina*
68	Buttonwoods and other hardwoods with *Sporobolus*
69	Open hammock w/ some *Cladium*; patches of mangroves; some buttonwoods w/ *Sporobolus*
70	Buttonwoods w/ *Borrichia* & *Sporobolus*, some *Spartina*; patches of mangroves
71	Overgrown road bordered by mangroves; thick hardwoods to east w/ little grass
72	Thick buttonwood near road, opens toward mangroves; *Borrichia* and *Sporobolus* understory
73	Buttonwood savannah (*Sporobolus*, *Borrichia* understory); islands of hammock.
74	Hammock & thick buttonwoods w/ *Sporobolus* understory
75	Not accessible -- "No trespassing" signs
76	Buttonwoods w/ sedges/*Sporobolus* understory, thick in some areas but open/rocky in others.
77	Not accessible -- "No trespassing" signs
78	Not surveyed.
79	Freshwater hardwoods; *Cladium* understory
80	Buttonwood transitional area with rocky ground, little grass.
81	Buttonwoods with *Sporobolus* as primary groundcover
82	Field of *Batis maritma* w/ scattered *Avicennia gerimans*; poor habitat
83	Freshwater hardwoods w/ sparse sawgrass, little cover.
84	Buttonwoods with *Sporobolus* and *Distichilis* (some mangrove spp.)
85	Freshwater marsh dominated by sawgrass
86	Mostly freshwater hardwoods (*Conocarpus*, *Cladium*, other trees) w/ some freshwater pine
87	Buttonwoods w/ *Sporobolus*, bordering hammock; lacks cover
88	Freshwater hardwoods with *Cladium* to south; a narrow buttonwood transition zone to north
89	Beach berm with hammock and some open, grassy areas
90	Freshwater hardwoods and *Cladium* marsh
91	Not surveyed.
92	Poor habitat; fairly open, mostly low marsh w/ scattered mangroves/buttonwoods; a few *S. spartinae*
93	Odd mosaic of hammock and buttonwood w/ some mangroves
94	Buttonwood fringe bordering/intergrading w/ hammock; *Sporobolus* and *Borrichia* understory

Table B.2. (continued)

Patch	Description
95	Buttonwoods w/ *Sporobolus*; many dead trees
96	Poor habitat; open buttonwood savanna w/ short trees/shrubs; many dead trees; *Sporobolus*/key grass
97	Not surveyed.
98	Not surveyed.
99	Buttonwoods/*Sporobolus* to north; "islands" of hammock, buttonwoods, and *Spartina spartinae* in south
100	Not surveyed.
101	Not surveyed.
102	Buttonwoods, primarily *Sporobolus* understory
103	Beach berm with little grass, many invasive exotics.
104	Thin transition zone between intertidal marsh and hammock
105	Patches of buttonwood and hammock with some low, sparse *Spartina*; surrounded by intertidal marsh
106	*Sporobolus* and scattered *Spartina* with fairly dense buttonwoods and patches of hammock species
107	Thick *spartina* and *Borrichia frutescens*
108	*Spartina* and *Borrichia* on a low ridge surrounded by low marsh; many dead *Borrichia*
109	Mostly *Batis* spp. with one patch of *Borrichia* and grasses; probable hurricane impact
110	Beach berm hammock w/ no grass, plus small area of buttonwood w/ *Sporobolus*/*Batis*
111	Freshwater wetland dominated by *Cladium* and buttonwoods
112	Patch of buttonwoods w/ sparse grass; surrounded by intertidal marsh and dwarf mangroves
113	Mowed back yard of a house; no longer habitat
114	Intertidal marsh (*Monanthochloe*, *Batis*) & open *Sporobolus* marsh with sparse *Borrichia*; poor habitat
115	Freshwater hardwoods in south, transitions to buttonwoods in north
116	Buttonwood transition zone surrounding (and mixed with) hammock
117	Freshwater hardwoods, freshwater marsh (*Cladium*), and freshwater pine
118	Mosaic of buttonwoods, intertidal marsh, & mangroves
119	Mosaic of buttonwoods w/ *Sporobolus*, mangroves & intertidal marsh; some *Borrichia frutescens* & *Batis*
120	Beach berm w/ *Pithecellobium* and seven year apple; also buttonwoods w/ *Sporobolus* and *Batis*
121	Open areas grassy and intertidal marsh w/ patches of buttonwoods; surrounded by *Batis* and mangroves.
122	*Cladium* marsh to the north, Buttonwoods to the south and southwest
123	Buttonwoods with *Sporobolus* and *Borrichia frutescens*
124	Buttonwoods w/ *Sporobolus*, some *Spartina spartinae*; *Batis* and some mangroves to north
125	Buttonwood, joewood, and some hammock veg with *Sporobolus*; surrounded by intertidal marsh

Table B.2. (continued)

Patch	Description
126	Mostly buttonwood savanna with *Sporobolus* and some *Borrichia*
127	Buttonwoods and other trees (e.g. saffron plum) w/ *Sporobolus*
128	Buttonwoods, joewood, wild dilly; some *Sporobolus* and thin *Spartina*; sparse cover
129	*Spartina patens* & *spartinae* w/ some hammock spp. and wild cotton
130	Mosaic of buttonwoods and saltmarsh w/ *Sporobolus* and *Borrichia frutescens*
131	Most of this area seems to have been mechanically cleared
132	Long buttonwood/saltmarsh transition zone
133	Several pellet groups in a freshwater marsh
134	Fairly extensive freshwater marsh
135	Several pellet groups in a freshwater marsh
136	Small sawgrass wetland bordered by hammock and pineland
137	Freshwater marsh and freshwater hardwoods
138	Mosaic of freshwater hardwoods, freshwater marsh, hammock, and pineland
139	*Spartina patens* marsh and some buttonwoods with *Sporobolus* understory
140	Buttonwoods w/ grassy understory; disturbed area in process of restoration
141	Mangroves and a few buttonwood areas surrounding USFWS headquarters
142	*Spartina spartinae* and *Borrichia frutescens* surrounding *Pithecellobium guadalupense*
143	Tall *Cladium* surrounding freshwater hardwoods
144	*Spartina* and *Borrichia frutescens* surrounded by intertidal marsh
145	Buttonwoods and mangroves w/ *Distichilis* and *Sporobolus*
146	Buttonwoods, mangroves, saffron plum; *Sporobolus*, *Borrichia arborescens*, some *Fimbristylis castanea*
147	Buttonwoods w/ *Sporobolus* ground cover
148	Freshwater pine and freswater hardwoods to north; buttonwoods and hammock to the south
149	Much *Borrichia frutescens*
150	Buttonwoods w/ *Sporobolus* and some *Borrichia frutescens* and *Batis* bordering mangroves
151	Buttonwoods, *Borrichia*, *Sporobolus*, and some *Spartina* surrounding a patch of hammock
152	Buttonwoods and grassy saltmarsh to east; Eleocharis marsh with mangrove spp. to west
153	*Spartina patens* and *spartinae* surrounded by runway and a wide ditch
154	Buttonwoods w/ thick *Sporobolus* and *Distichilis*
155	Buttonwood fringe w/ *Spartina patens* surrounding *Eleocharis* marsh
156	Some buttonwood/*Sporobolus*/*Schizachyrium*; mostly scarified from *Casuarina* removal

Table B.2. (continued)

Patch	Description
157	Grassy saltmarsh: mosaic of *Borrichia frutecens*/*Sporobolus*, *Fimbristylis*, *Spartina spartinae*, more
158	Freshwater hardwoods (*Conocarpus*/*Cladium*) with some areas of mangroves
159	Ridge of buttonwoods (in the east) and grassy saltmarsh (in the west, w/ abundant *Spartina*)
160	Mosaic of grassy saltmarsh and more mesic grassland with patches of tall, thick *Borrichia frutescens*
161	Grassy saltmarsh with *Spartina spartinae* and other grasses
162	Buttonwood with mostly *Sporobolus* and *Borrichia* understory, some *Spartina*
163	Narrow buttonwood fringe w/ *Sporobolus*, *Salicornia*, *Borrichia*, and/or rocky ground cover
164	Mosaic of buttonwoods, mangroves, and a few hammock spp.; *Batis*, *Borrichia*, *Salicornia*, *Sporobolus*
165	Narrow buttonwood transition; mostly *Sporobolus* ground cover; most pellets on boards or near hammock
166	Open, w/ low buttonwoods, *Sporobolus*, *Borrichia*, *Monanthochloe*, *Salicornia*; pellets near mangroves
167	Buttonwoods w/ lush *Sporobolus* understory; some *Batis* in small depressions
168	Buttonwood savanna w/ *Sporobolus*; few bunch grasses; scattered mangroves with *Batis* understory
169	Strip of *Spartina spartinae* along taxiway; thick peppers and buttonwoods; a patch of hammock
170	Patch of mangroves w/ a *Spartina spartinae* patch to the east; also a narrow buttonwood fringe
171	Open, grassy areas plus *Borrichia frutescens* fields, *Schinus*, and other trees/shrubs
172	*Leucaena* clumps with grasses in between
173	Buttonwoods w/ *Fimbrystilis*; some *Cladium*; fields of *Eleocharis*; mangroves (some w/ *Distichilis*)
174	Buttonwoods w/ mostly *Fimbrystilis*/*Eleocharis* understory; some areas sparse understory
175	Mangroves (esp. *Laguncularia*) and some buttonwoods and grass
176	Buttonwoods w/ patches of *Borrichia frutescens* and *Spartina spartinae*
177	Mangroves and buttonwoods w/ *Salicornia* and a few grasses; low quality habitat
178	Buttonwoods and mangroves, including a mangrove-covered "spit"
179	Buttonwoods bordering mangroves; *Sporobolus* groundcover; narrow strip of *Borrichia*
180	*Cladium* depressions surrounded by hammock
181	Thick *Sporobolus* under buttonwoods; intergrades with hammock
182	Saffron plum and other buttonwood/hammock species surrounded by *Sporobolus*
183	Buttonwoods, *Distichilis*, and *Sporobolus* bordering the 3 mangrove spp.
184	Thick cover of *Fimbristylis castanea*
185	Dry open saw grass area in south; thicker cover in north
186	Sawgrass depression surrounded by hammock
187	Freshwater hardwoods with a thick cover of *Cladium*; *Conocarpus* canopy

Table B.2. (continued)

Patch	Description
188	Buttonwoods and mangroves with thick *Sporobolus* and *Distichilis*
189	Buttonwoods mixed w/ some hammock spp., plus freshwater hardwoods (*Cladium*) in northeast
190	Intertidal marsh with buttonwoods and thick *Batis* ground cover
191	Buttonwoods with *Sporobolus* understory
192	Disturbed area with open *Sporobolus* marsh surrounded by thick buttonwoods/hammock
193	Good cover for rabbits with areas with *Spartina spartinae* and *Spartina patens*
194	Mostly intertidal marsh with some buttonwoods
195	Beach berm with *Sporobolus* and other grasses, shrubs
196	*Spartina spartinae* and buttonwoods w/ *Sporobolus*; some hammock spp.
197	Patch of buttonwood/hammock surrounded by *Spartina spartinae* and *Sporobolus*
198	Freshwater hardwoods w/ thick cover of *Cladium* and *Fimbristylis*
199	Mosaic of *Fimbristylis castanea*, buttonwoods, hammock spp. and intertidal marsh
200	Buttonwoods w/ *Sporobolus*, *Distichilis*, *Borrichia frutescens* groundcover.
201	Buttonwoods w/ *Sporobolus* and some sparse *Spartina*; sometimes hammock-like w/ little groundcover
202	Buttonwoods w/ some hammock species; *Sporobolus* or leaf litter as groundcover
203	Buttonwoods with *Sporobolus*, *Distichilis*, *Borrichia frutescens* understory.
204	A mosaic of buttonwood, hammock, and mangroves
205	Buttonwoods and mangroves surrounding a building
206	Buttonwood with mostly *Sporobolus* and *Borrichia* understory; some *Fimbristylis*
207	Patches of *Spartnia spartinae* with a few hardwoods
208	Fresshwater marsh with tall, thick sawgrass; floods easily
209	Freshwater marsh with sawgrass, *Eleocharis*, and *Typha*. Disturbed buttonwoods to south
210	Field of *Borrichia frutescens* w/ a few *Spartina spartinae* near road & *Sporobolus* along water
211	Mostly *Spartina patens* with some *Borrichia frutescens*, *Batis*, and a few *Spartina spartinae*.
212	Buttonwoods with *Borrichia frutescens* & *Sporobolus*
213	Buttonwoods w/ *Sporobolus* understory
214	Mix of freshwater marsh and freshwater hardwoods; *Cladium* dominates
215	Freshwater hardwoods w/ *Conocarpus* & tall, thick *Cladium*
216	Freshwater hardwoods w/ *Conocarpus* & *Cladium* (mostly tall, thick)
217	Freshwater hardwoods w/ *Conocarpus* & *Cladium* (mostly tall, thick)
218	Freshwater hardwoods & marsh; *Cladium* (of varying height) dominates

Table B.2. (continued)

Patch	Description
219	Freshwater hardwoods and freshwater marsh (*Cladium* dominates)
220	Freshwater hardwoods in center surrounded by thick *Cladium* marsh
221	Freshwater hardwoods & marsh; *Cladium* varies in height
222	Freshwater hardwoods and marsh; *Cladium*/buttonwood dominate; *Cladium* varies in height
223	Freshwater hardwood center w/ mostly tall, thick *Cladium*
224	Freshwater hardoods to east; freshwater marsh to west; freshwater pine to north; *Cladium* dominates
225	Freshwater hardwoods; buttonwood and tall, thick *Cladium* dominates
226	*Cladium* marsh around margins, freshwater hardwood center
227	Freshwater hardwoods w/ *Conocarpus*, *Cladium*; deep organic muck in center
228	Narrow berm of buttonwoods and *Avicennia gerimans*; *Sporobolus*, *Batis* in sparse understory
229	Narrow buttonwood fringe w/ low *Sporobolus* and a few sparse *Spartina*; poor habitat

APPENDIX C

TRAPPING OF LOWER KEYS MARSH RABBITS

Trapping occurred on a nearly continuous basis in 12 potential source populations from October 2001–August 2002 during a LKMR reintroduction project, resulting in 109 captures (70 individuals) over 3,884 trap nights (1 rabbit per 35.6 trap nights, capture probability = 2.8%) (Tables C.1–C.2). Trapping without drift fences accounted for 3,159 of the trap nights and 98 of the captures (1 rabbit per 32.2 trap nights, capture probability 3.1%). Traps were baited for 206 trap nights, but only 1 rabbit was captured during this time (capture probability = 0.5%). Unbaited traps had a capture probability of 1 rabbit per 30.4 trap nights (3.3%).

During trapping for the reintroduction program, 150 drift fence arrays were set, totaling 725 trap nights. Eleven rabbits were captured in the drift fence arrays (1 rabbit per 13.6 arrays, capture probability 7.3% per array; 1 rabbit per 65.9 trap nights, 1.5% per trap night). Using drift fences allowed trapping of rabbits in open areas without thick vegetation, where unbaited traps alone would have had a low probability for success.

In addition, drift fences were used to selectively target individual rabbits after the reintroduction from August 2002–October 2002 (Table C.2). Attempts to replace failed transmitters on Little Pine Key resulted in 2 rabbit captures using 98 trap nights in 16 drift fence arrays. One eastern box turtle and 2 black rats also were captured. Forty-nine trap nights in 6 drift fence arrays were used to recapture a rabbit on Big Torch Key.

Ticks were occasionally discovered on and around the head of captured rabbits. The rabbit tick (*Haemaphysalis leporispalustris*) was the only species found.

Table C.1. Seventy individual Lower Keys marsh rabbits were trapped between November 2001–October 2002 in the Lower Keys of Florida, USA.

Identification	Patch ID	Sex	Age class	Times captured
421C0A5963	33	Female	Adult	1
4225413002	160	Female	Adult	1
422543030F	29	Female	Adult	2
422554031C	157	Female	Adult	3
4225564718	29	Female	Adult	1
4225565F20	29	Female	Adult	1
4225621C39	8	Female	Adult	2
4225635412	8	Female	Adult	2
4226092B08	160	Female	Adult	1
4229032A5E	157	Female	Adult	1
4229090F54	8	Female	Adult	1
422F2A6C76	33	Female	Adult	2
422F442714	33	Female	Adult	1
422F4B304F	122	Female	Adult	2
4230370224	162	Female	Adult	3
42304D7610	122	Female	Adult	2
4230517704	162	Female	Adult	1
4230556B2A	33	Female	Adult	1
deadF1	29	Female	Adult	1
injuredF1	29	Female	Adult	1
juviF2	29	Female	Juvenile	1
juviF3	29	Female	Juvenile	1
42254F545E	10	Female	Subadult	2
4225705D68	29	Female	Subadult	1
42286E5E1D	33	Female	Subadult	1
4230332B4E	122	Female	Subadult	1
4230433B2A	33	Female	Subadult	1
421B7A4219	33	Male	Adult	2
422542377C	157	Male	Adult	1
4225434C3D	157	Male	Adult	3
42254C2F78	33	Male	Adult	1
4225523E75	9	Male	Adult	2
4225524403	160	Male	Adult	1
42255C534C	29	Male	Adult	4
42256B443B	29	Male	Adult	1
42256C6938	29	Male	Adult	1
4225710E6C	33	Male	Adult	1
4225757535	157	Male	Adult	2
4225762E10	29	Male	Adult	1
42257B616D	8	Male	Adult	1
42257C2452	33	Male	Adult	2
42257C2666	157	Male	Adult	2
42257D217F	9	Male	Adult	1

Table C.1. (continued)

Identification	Patch ID	Sex	Age class	Times captured
42260A2E42	29	Male	Adult	2
42260E0F6E	33	Male	Adult	2
42286C1148	160	Male	Adult	1
422873767B	8	Male	Adult	2
42287E376E	157	Male	Adult	3
422F2C0118	122	Male	Adult	2
422F2D2602	122	Male	Adult	1
422F2F5576	33	Male	Adult	1
422F31447B	162	Male	Adult	1
422F3F560D	33	Male	Adult	1
422F4A3178	33	Male	Adult	1
423046022A	52	Male	Adult	1
423052236A	122	Male	Adult	2
421B773145	122	Male	Juvenile	1
422F297E4F	122	Male	Juvenile	1
juviM1	29	Male	Juvenile	1
42253B6516	29	Male	Subadult	1
42254C6E22	8	Male	Subadult	2
4225644627	29	Male	Subadult	3
42256C7946	29	Male	Subadult	1
4225704550	10	Male	Subadult	3
4225716E16	8	Male	Subadult	5
42287B4546	29	Male	Subadult	4
42302B3F11	122	Male	Subadult	3
42304B1D50	122	Male	Subadult	1
4230532D16	162	Male	Subadult	1
juviF1	29	Unknown	Juvenile	1

Table C.2. One hundred and twelve captures of Lower Keys marsh rabbits were made from October 2001–October 2002 in the Lower Keys of Florida, USA.

Date	Event	PIT tag	Transmitter ID	Patch ID	Previously captured?	Weight (g)	Sex	Age class	Pregnant?
17-Oct-2001	1	4225621C39	150.224	8	No	1,480	Female	Adult	No
30-Oct-2001	2	4225716E16	150.284	8	No	830	Male	Subadult	No
1-Nov-2001	3	42254C6E22	150.404	8	No	910	Male	Subadult	No
8-Nov-2001	4	422873767B	150.342	8	No	1,050	Male	Adult	Not Applicable
12-Nov-2001	5	4225716E16	150.264	8	Yes	830	Male	Subadult	Not Applicable
13-Nov-2001	6	4229090F54	150.204	8	No	1,300	Female	Adult	
14-Nov-2001	7	42254C6E22	150.183	8	Yes	860	Male	Subadult	Not Applicable
15-Nov-2001	8	4225635412	150.363	8	No	1,320	Female	Adult	
16-Nov-2001	9	4225716E16	150.264	8	Yes	820	Male	Subadult	Not Applicable
20-Nov-2001	10	4225434C3D	150.704	157	No	1,040	Male	Adult	Not Applicable
20-Nov-2001	11	42287E376E	150.764	157	No	1,050	Male	Adult	Not Applicable
21-Nov-2001	12	4225757535	150.302	157	No	1,090	Male	Adult	Not Applicable
21-Nov-2001	13	42257C2666	150.804	157	No	1,000	Male	Adult	Not Applicable
21-Nov-2001	14	422554031C	150.444	157	No	1,130	Female	Adult	No
22-Nov-2001	15	4225434C3D	150.704	157	Yes	985	Male	Adult	Not Applicable
26-Nov-2001	16	42287E376E	150.384	157	Yes	1,155	Male	Adult	Not Applicable
26-Nov-2001	17	4229032A5E	150.464	157	No	1,160	Female	Adult	No
27-Nov-2001	18	42257C2666	150.804	157	Yes	1,030	Male	Adult	Not Applicable
27-Nov-2001	19	4225434C3D	150.704	157	Yes		Male	Adult	Not Applicable
30-Nov-2001	20	4225716E16	150.784	9	Yes	820	Male	Subadult	Not Applicable
30-Nov-2001	21	4225523E75	150.564	9	No	1,170	Male	Adult	Not Applicable
6-Dec-2001	22	4225523E75	150.484	9	Yes	1,135	Male	Adult	Not Applicable
6-Dec-2001	23	422873767B	150.764	9	Yes	1,000	Male	Adult	Not Applicable
6-Dec-2001	24	42257D217F	150.584	9	No	1,080	Male	Adult	Not Applicable
14-Dec-2001	25	4225635412	150.504	8	Yes	1,070	Female	Adult	No
14-Dec-2001	26	42257B616D	n/a	8	No	1,060	Male	Adult	Not Applicable

Table C.2. (continued)

Date	Event	PIT tag	Transmitter ID	Patch ID	Previously captured?	Weight (g)	Sex	Age class	Pregnant?
17-Dec-2001	27	42287E376E	150.724	157	Yes	1,130	Male	Adult	Not Applicable
19-Dec-2001	28	422542377C	n/a	157	No	1,160	Male	Adult	Not Applicable
19-Dec-2001	29	422554031C	150.604	157	Yes	1,080	Female	Adult	No
19-Dec-2001	30	4225621C39	150.224	9	Yes	1,330	Female	Adult	No
31-Dec-2001	31	42254F545E	150.624	10	No	900	Female	Subadult	No
4-Jan-2002	32	4225704550	n/a	10	No	720	Male	Subadult	Not Applicable
5-Jan-2002	33	4225704550	n/a	10	Yes	720	Male	Subadult	Not Applicable
7-Jan-2002	34	4225704550	n/a	10	Yes	720	Male	Subadult	Not Applicable
7-Jan-2002	35	42254F545E	150.624	10	Yes		Female	Adult	No
25-Jan-2002	36	42256C7946	150.644	29	No	990	Male	Subadult	Not Applicable
25-Jan-2002	37	4225564718		29	No		Female	Adult	No
27-Jan-2002	38	422554031C	150.604	157	Yes	1,050	Female	Adult	No
29-Jan-2002	39	4225757535	150.524	157	Yes	1,020	Male	Adult	Not Applicable
30-Jan-2002	40	42287B4546	n/a	29	No	690	Male	Subadult	Not Applicable
31-Jan-2002	41	juviF1		29	No	340	Unknown	Juvenile	Not Applicable
31-Jan-2002	42	4225762E10		29	No	1,090	Male	Adult	Not Applicable
31-Jan-2002	43	4225565F20	150.624	29	No	1,130	Female	Adult	No
31-Jan-2002	44	42255C534C	n/a	29	No	1,010	Male	Adult	Not Applicable
31-Jan-2002	45	42256C6938	150.704	29	No	1,040	Male	Adult	Not Applicable
1-Feb-2002	46	42255C534C	n/a	204	Yes	960	Male	Adult	Not Applicable
1-Feb-2002	47	juviM1		29	No	360	Male	Juvenile	Not Applicable
1-Feb-2002	48	42287B4546	n/a	29	Yes	680	Male	Subadult	Not Applicable
1-Feb-2002	49	42253B6516	n/a	29	No	990	Male	Subadult	Not Applicable
5-Feb-2002	50	42260A2E42		29	No	1,110	Male	Adult	Not Applicable
5-Feb-2002	51	4225644627		29	No	800	Male	Subadult	Not Applicable
5-Feb-2002	52	42287B4546		29	Yes		Male	Subadult	Not Applicable
6-Feb-2002	53	42260A2E42		29	Yes	1,120	Male	Adult	Not Applicable
6-Feb-2002	54	4225644627		29	Yes	780	Male	Subadult	Not Applicable
6-Feb-2002	55	422543030F		204	No	1,180	Female	Adult	No
6-Feb-2002	56	juviF2		204	No	520	Female	Juvenile	No

Table C.2. (continued)

Date	Event	PIT tag	Transmitter ID	Patch ID	Previously captured?	Weight (g)	Sex	Age class	Pregnant?
7-Feb-2002	57	422543030F		29	Yes	1,130	Female	Adult	No
7-Feb-2002	58	42287B4546		29	Yes	630	Male	Subadult	Not Applicable
8-Feb-2002	59	42256B443B		29	No	1,110	Male	Adult	Not Applicable
8-Feb-2002	60	42255C534C		204	Yes	970	Male	Adult	Not Applicable
8-Feb-2002	61	juviF3		29	No	550	Female	Juvenile	No
12-Feb-2002	62	4225644627		204	Yes	780	Male	Subadult	Not Applicable
13-Feb-2002	63	injuredF1		205	No		Female	Adult	No
13-Feb-2002	64	deadF1		205	No		Female	Adult	
13-Feb-2002	65	42255C534C		29	Yes	970	Male	Adult	Not Applicable
13-Feb-2002	66	4225705D68		204	No	890	Female	Subadult	No
28-Feb-2002	67	42260E0F6E	none	33	No	1,320	Male	Adult	Not Applicable
07-Mar-2002	68	42257C2452	none	33	No	1,220	Male	Adult	Not Applicable
13-Mar-2002	69	42254C2F78	150.544	33	No	1,080	Male	Adult	Not Applicable
14-Mar-2002	70	42286E5E1D	150.564	33	No	970	Female	Subadult	No
19-Mar-2002	71	4225710E6C	none	33	No	1,220	Male	Adult	Not Applicable
21-Mar-2002	72	42257C2452	151.603	33	Yes		Male	Adult	Not Applicable
26-Mar-2002	73	4225413002	151.620	160	No	1,110	Female	Adult	No
26-Mar-2002	74	4226092B08	151.583	160	No	1,160	Female	Adult	Yes
26-Mar-2002	75	42286C1148	none	160	No	1,210	Male	Adult	Not Applicable
26-Mar-2002	76	4225524403	none	160	No	1,180	Male	Adult	Not Applicable
30-Mar-2002	77	4225716E16	150.784	8	Yes	960	Male	Subadult	Not Applicable
03-Apr-02	78	422F31447B	151.491	162	No	1,190	Male	Adult	Not Applicable
03-Apr-2002	79	4230370224	151.620	162	No	1,040	Female	Adult	No
05-Apr-2002	80	4230517704	151.552	162	No	1,000	Female	Adult	No
05-Apr-02	81	4230532D16	none	162	No	600	Male	Subadult	No
22-May-2002	82	423052236A	151.252	122	No	1,120	Male	Adult	Not Applicable
22-May-2002	83	422F2C0118	151.712	122	No	1,020	Male	Adult	Not Applicable
22-May-2002	84	421B773145	none	122	No	260	Male	Juvenile	Not Applicable
22-May-2002	85	42304D7610	151.673	122	No	1,140	Female	Adult	No
23-May-2002	86	422F297E4F	none	122	No	220	Male	Juvenile	Not Applicable

Table C.2. (continued)

Date	Event	PIT tag	Transmitter ID	Patch ID	Previously captured?	Weight (g)	Sex	Age class	Pregnant?
23-May-2002	87	4230332B4E	none	122	No	960	Female	Subadult	No
24-May-2002	88	423052236A	151.252	122	Yes		Male	Adult	Not Applicable
24-May-2002	89	42304D7610	151.673	122	Yes		Female	Adult	No
27-May-2002	90	422F2C0118	151.712	122	Yes		Male	Adult	Not Applicable
05-Jun-2002	91	42304B1D50	none	122	No	700	Male	Subadult	Not Applicable
12-Jun-2002	92	422F2D2602	150.804	122	No	1,000	Male	Adult	Not Applicable
14-Jun-2002	93	42302B3F11	none	122	No	800	Male	Subadult	Not Applicable
18-Jun-2002	94	42302B3F11	none	122	Yes	800	Male	Subadult	Not Applicable
22-Jun-2002	95	42302B3F11	none	122	Yes		Male	Subadult	Not Applicable
25-Jun-2002	96	422F4B304F	150.784	122	No	1,130	Female	Adult	No
29-Jun-2002	97	423046022A	none	52	No	1,090	Male	Adult	Not Applicable
11-Jul-2002	98	4230370224	151.273	99	Yes	1,150	Female	Adult	No
16-Jul-2002	99	422F2A6C76	151.213	33	No	1,360	Female	Adult	No
18-Jul-2002	100	422F442714	151.752	33	No	1,360	Female	Adult	No
18-Jul-2002	101	422F2A6C76	151.213	33	Yes		Female	Adult	No
23-Jul-2002	102	422F3F560D	none	33	No	1,260	Male	Adult	Not Applicable
25-Jul-2002	103	422F2F5576	151.652	33	No	1,260	Male	Adult	Not Applicable
02-Aug-2002	104	421C0A5963	151.532	33	No	1,000	Female	Adult	No
04-Aug-2002	105	4230556B2A	none	33	No	1,150	Female	Adult	No
07-Aug-2002	106	422F4A3178	none	33	No	1,070	Male	Adult	Not Applicable
07-Aug-2002	107	4230433B2A	none	33	No	700	Female	Subadult	No
08-Aug-2002	108	421B7A4219	none	33	No	1,240	Male	Adult	Not Applicable
15-Aug-2002	109	42260E0F6E	151.694	33	Yes	1,260	Male	Adult	Not Applicable
15-Aug-2002	110	421B7A4219	none	33	Yes		Male	Adult	Not Applicable
03-Oct-2002	111	4230370224	151.273	99	Yes	1,160	Female	Adult	No
24-Oct-2002	112	422F4B304F	151.233	79	Yes		Female	Adult	No

APPENDIX D

POTENTIAL-HABITAT-SCORE RESULTS

Table D.1. Patch-scale scores for a Potential-Habitat-Score system used to evaluate potential populations of the Lower Keys marsh rabbit in the Lower Keys of Florida, USA, in 2001–2003. Patch scale scores were calculated based on 3 criteria: escape/nesting cover, herbaceous cover for foraging, and susceptibility to seasonal flooding.

Patch	Cover	Food (herbaceous cover)	Flooding	Total patch score
4	30	45	10	85
11	30	45	10	85
13	45	45	10	100
17	15	45	10	70
28	30	45	10	85
36	30	45	10	85
37	15	45	0	60
38	30	45	0	75
39	30	45	0	75
40	30	45	0	75
41	30	45	10	85
42	15	45	10	70
43	30	45	10	85
44	45	45	10	100
45	15	45	10	70
46	15	45	10	70
47	15	45	10	70
48	45	45	10	100
49	30	45	10	85
50	30	45	10	85
51	15	45	10	70
56	15	45	10	70
57	45	45	10	100
58	15	45	10	70
59	15	45	10	70
60	15	0	10	25
63	15	45	10	70
64	15	45	10	70
65	15	45	0	60
66	15	45	10	70
67	15	45	10	70
68	15	45	10	70
69	15	45	10	70
70	15	45	10	70
71	15	0	10	25
72	30	45	10	85
73	30	45	10	85
74	15	45	10	70
76	15	0	10	25

Table D.1. (continued)

Patch	Cover	Food (herbaceous cover)	Flooding	Total patch score
79	15	45	10	70
80	15	45	10	70
81	15	45	10	70
84	30	45	10	85
87	15	45	10	70
89	15	45	10	70
92	15	45	10	70
94	15	45	10	70
99	30	45	10	85
103	15	0	10	25
104	15	45	10	70
109	15	0	10	25
110	15	45	10	70
112	15	45	10	70
114	0	45	10	55
120	15	45	10	70
124	30	45	10	85
125	15	45	10	70
127	15	45	10	70
128	15	45	10	70
129	45	45	10	100
130	30	45	10	85
142	45	45	10	100
145	30	45	10	85
146	15	45	10	70
147	15	45	10	70
149	15	45	10	70
150	30	45	10	85
154	15	45	10	70
156	0	45	10	55
159	45	45	10	100
163	15	45	10	70
164	30	45	10	85
167	15	45	10	70
168	30	45	10	85
179	15	45	10	70
180	30	45	0	75
181	30	45	10	85
182	15	45	10	70
183	15	45	10	70
184	45	45	10	100
185	30	45	0	75
186	30	45	0	75
187	30	45	10	85
188	30	45	10	85

Table D.1. (continued)

Patch	Cover	Food (herbaceous cover)	Flooding	Total patch score
189	15	45	10	70
190	15	45	10	70
195	15	45	10	70
198	15	45	10	70
199	30	45	10	85
200	30	45	10	85
201	15	45	10	70
203	15	45	10	70
208	30	45	0	75
209	15	45	10	70
210	30	45	10	85
211	45	45	10	100
212	15	45	10	70
213	15	45	10	70
214	30	45	0	75
215	30	45	0	75
216	30	45	0	75
217	30	45	0	75
218	30	45	0	75
219	30	45	0	75
220	30	45	0	75
221	30	45	0	75
222	30	45	0	75
223	30	45	0	75
224	30	45	0	75
225	30	45	0	75
226	30	45	0	75
227	30	45	0	75
229	0	45	10	55

Table D.2. Total-area-available-to-a-potential-population-scale (TAPP) score for a Potential-Habitat-Scoring system used to evaluate potential populations of the Lower Keys marsh rabbit in the Lower Keys of Florida, USA, in 2001–2003. The TAPP score was the sum of 2 criteria: the total area of constituent habitat patches and the area-weighted mean patch-scale score of constituent patches.

Potential population	Area xcore	Mean patch score	TAPP Score
4	20	59.5	79.5
11	20	67.9	87.9
17	20	49.0	69.0
28	0	59.5	59.5
36	30	59.5	89.5
37	30	48.3	78.3
39	20	52.1	72.1
40	20	52.5	72.5
41	20	59.5	79.5
42	30	49.0	79.0
43	20	59.5	79.5
44	20	70.0	90.0
45	20	49.0	69.0
46	20	49.5	69.5
47	20	49.0	69.0
48	20	70.0	90.0
49	30	55.8	85.8
50	20	59.5	79.5
51	30	49.0	79.0
56	20	49.0	69.0
57	30	57.9	87.9
58	30	49.0	79.0
59	20	49.0	69.0
60	30	17.5	47.5
63	20	49.0	69.0
64	20	49.0	69.0
65	10	42.0	52.0
66	20	49.0	69.0
67	30	49.0	79.0
68	20	49.0	69.0
69	20	49.0	69.0
70	30	54.1	84.1
71	10	17.5	27.5
76	20	17.5	37.5
81	20	49.0	69.0
84	30	59.5	89.5
92	20	49.0	69.0
94	20	49.0	69.0
99	30	59.5	89.5
103	20	17.5	37.5

Table D.2. (continued)

Potential population	Area score	Mean patch score	TAPP score
104	20	49.0	69.0
109	20	17.5	37.5
110	30	49.0	79.0
112	20	49.0	69.0
114	10	38.5	48.5
120	20	49.0	69.0
125	20	49.0	69.0
127	20	49.0	69.0
128	20	49.0	69.0
129	20	70.0	90.0
130	20	59.5	79.5
142	10	70.0	80.0
147	10	49.0	59.0
150	20	59.5	79.5
154	20	49.0	69.0
159	20	70.0	90.0
163	30	49.0	79.0
164	10	59.5	69.5
167	20	49.0	69.0
168	20	59.5	79.5
179	30	49.0	79.0
181	20	57.8	77.8
184	10	70.0	80.0
185	20	52.5	72.5
186	10	52.5	62.5
188	30	59.5	89.5
189	30	49.0	79.0
199	10	59.5	69.5
200	10	59.5	69.5
201	20	49.0	69.0
209	10	49.0	59.0
211	0	49.0	49.0
212	10	49.0	59.0
213	10	52.5	62.5
214	20	52.5	72.5
221	10	52.5	62.5
222	20	52.5	72.5
224	20	52.5	72.5
225	20	59.5	79.5
228	30	38.5	68.5

Table D.3. Landscape-scale scores for a Potential-Habitat-Score system used to evaluate potential populations of the Lower Keys marsh rabbit in the Lower Keys of Florida, USA, in 2001–2003. The landscape-scale score was calculated by summing the scores for 4 criteria: the proximity index, connectivity to neighbors, distance to human development, and distance to roads.

Potential population	Proximity index	Connectivity	Distance to development	Distance to roads	Landscape score
4	20.0	20	10	30	80.0
11	6.7	0	0	15	21.7
17	13.3	20	0	0	33.3
28	13.3	20	20	30	83.3
36	6.7	20	20	30	76.7
37	20.0	20	0	15	55.0
39	20.0	20	0	0	40.0
40	13.3	20	0	15	48.3
41	6.7	20	0	15	41.7
42	6.7	20	10	15	51.7
43	6.7	0	0	15	21.7
44	6.7	20	0	15	41.7
45	0.0	20	0	15	35.0
46	6.7	20	10	15	51.7
47	13.3	20	0	15	48.3
48	13.3	20	0	15	48.3
49	13.3	20	10	15	58.3
50	20.0	20	0	15	55.0
51	13.3	20	0	15	48.3
56	6.7	0	0	15	21.7
57	6.7	20	0	0	26.7
58	20.0	20	10	15	65.0
59	0.0	20	10	15	45.0
60	13.3	20	10	30	73.3
63	20.0	20	10	30	80.0
64	13.3	20	20	30	83.3
65	6.7	20	0	15	41.7
66	0.0	20	20	15	55.0
67	6.7	20	10	30	66.7
68	6.7	20	20	30	76.7
69	6.7	20	10	30	66.7
70	6.7	20	0	15	41.7
71	13.3	20	0	15	48.3
76	6.7	20	0	15	41.7
81	13.3	20	10	30	73.3
84	13.3	20	10	30	73.3
92	13.3	20	30	30	93.3
94	6.7	20	30	30	86.7
99	13.3	20	30	30	93.3
103	0.0	0	30	30	60.0
104	20.0	20	10	30	80.0

Table D.3. (continued)

Potential population	Proximity	Connectivity	Distance to development	Distance to roads	Landscape score
109	6.7	20	20	30	76.7
110	0.0	0	30	30	60.0
112	6.7	20	10	15	51.7
114	13.3	20	20	30	83.3
120	0.0	0	30	30	60.0
125	20.0	20	10	15	65.0
127	20.0	20	10	30	80.0
128	6.7	20	20	30	76.7
129	13.3	20	30	30	93.3
130	13.3	20	0	15	48.3
142	13.3	20	30	30	93.3
147	6.7	20	10	30	66.7
150	13.3	20	30	30	93.3
154	13.3	20	10	15	58.3
159	13.3	20	30	30	93.3
163	0.0	0	30	30	60.0
164	0.0	0	30	30	60.0
167	6.7	20	20	30	76.7
168	0.0	0	30	30	60.0
179	6.7	20	10	15	51.7
181	13.3	20	10	30	73.3
184	6.7	20	0	15	41.7
185	6.7	20	0	0	26.7
186	13.3	20	0	15	48.3
188	13.3	20	10	30	73.3
189	13.3	20	0	15	48.3
199	13.3	20	20	30	83.3
200	6.7	20	20	30	76.7
201	13.3	20	20	30	83.3
209	6.7	20	0	0	26.7
210	6.7	20	0	0	26.7
212	13.3	20	30	30	93.3
213	13.3	20	30	30	93.3
214	20.0	20	10	30	80.0
221	20.0	20	0	30	70.0
222	20.0	20	10	30	80.0
224	13.3	20	0	30	63.3
225	6.7	20	0	30	56.7
229	0.0	20	20	30	70.0

Table D.4. Potential Habitat Scores for potential populations of the Lower Keys marsh rabbit in the Lower Keys of Florida, USA, in 2001–2003. The Potential Habitat Score was the mean of the total-area-available-to-a-potential-population-scale (TAPP) score and the landscape-scale score. Potential populations with a TAPP score $\geq$ 69, landscape scale score > 61, and Patch Habitat Score $\geq$ 75 were considered to be the most suitable for Lower Keys marsh rabbits. These high-ranked potential populations were highlighted below.

Potential population	TAPP score	Landscape score	Potential habitat score
129	90.0	93.3	91.7
159	90.0	93.3	91.7
99	89.5	93.3	91.4
142	80.0	93.3	86.7
150	79.5	93.3	86.4
36	89.5	76.7	83.1
84	89.5	73.3	81.4
188	89.5	73.3	81.4
92	69.0	93.3	81.2
4	79.5	80.0	79.8
213	62.5	93.3	77.9
94	69.0	86.7	77.8
199	69.5	83.3	76.4
214	72.5	80.0	76.3
222	72.5	80.0	76.3
212	59.0	93.3	76.2
64	69.0	83.3	76.2
201	69.0	83.3	76.2
181	77.8	73.3	75.6
63	69.0	80.0	74.5
104	69.0	80.0	74.5
127	69.0	80.0	74.5
200	69.5	76.7	73.1
68	69.0	76.7	72.8
128	69.0	76.7	72.8
167	69.0	76.7	72.8
67	79.0	66.7	72.8
49	85.8	58.3	72.1
58	79.0	65.0	72.0
28	59.5	83.3	71.4
81	69.0	73.3	71.2
168	79.5	60.0	69.8
110	79.0	60.0	69.5
163	79.0	60.0	69.5
229	68.5	70.0	69.3
48	90.0	48.3	69.2
225	79.5	56.7	68.1
224	72.5	63.3	67.9
69	69.0	66.7	67.8
50	79.5	55.0	67.3

Table D.4. (continued)

Potential population	TAPP score	Landscape score	Potential habitat score
125	69.0	65.0	67.0
37	78.3	55.0	66.6
221	62.5	70.0	66.3
114	48.5	83.3	65.9
44	90.0	41.7	65.8
42	79.0	51.7	65.3
179	79.0	51.7	65.3
164	69.5	60.0	64.8
120	69.0	60.0	64.5
130	79.5	48.3	63.9
154	69.0	58.3	63.7
51	79.0	48.3	63.7
189	79.0	48.3	63.7
70	84.1	41.7	62.9
147	59.0	66.7	62.8
66	69.0	55.0	62.0
184	80.0	41.7	60.8
46	69.5	51.7	60.6
41	79.5	41.7	60.6
60	47.5	73.3	60.4
40	72.5	48.3	60.4
112	69.0	51.7	60.3
47	69.0	48.3	58.7
57	87.9	26.7	57.3
109	37.5	76.7	57.1
59	69.0	45.0	57.0
39	72.1	40.0	56.1
186	62.5	48.3	55.4
11	87.9	21.7	54.8
45	69.0	35.0	52.0
17	69.0	33.3	51.2
43	79.5	21.7	50.6
185	72.5	26.7	49.6
103	37.5	60.0	48.8
65	52.0	41.7	46.8
56	69.0	21.7	45.3
209	59.0	26.7	42.8
76	37.5	41.7	39.6
71	27.5	48.3	37.9
211	49.0	26.7	37.8

APPENDIX E

PATCH RESTORATION NEEDS

Table E.1. Restoration needs for core habitat patches of the Lower Keys marsh rabbit.

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
1	East Rockland	NAFKW	occupied	2.6	trash	medium priority
2	East Rockland	NAFKW	occupied	0.9	none	
3	Boca Chica	NAFKW	occupied	1.7	none	
4	Boca Chica	NAFKW	potential	1.7	exotics	low priority
5	Geiger	NAFKW	occupied	1.1	exotics/habitat enhancement	medium priority
6	Boca Chica	NAFKW	occupied	0.5	exotics	low priority
7	Boca Chica	NAFKW	occupied	1.6	exotics/habitat enhancement	high priority
8	Boca Chica	NAFKW	occupied	4.3	exotics/habitat enhancement	high priority
9	Boca Chica	NAFKW	occupied	6.3	exotics	medium priority
10	Geiger	NAFKW	occupied	0.4	habitat enhancement	medium priority
11	Geiger	NAFKW	potential	1.0	exotics/predator control	low priority
12	Boca Chica	NAFKW	occupied	1.3	none	
13	Geiger	NAFKW	potential	3.7	predator control	low priority
14	Boca Chica	NAFKW	occupied	1.4	habitat enhancement	high priority
15	Boca Chica	NAFKW	occupied	2.5	exotics/trash	medium priority
16	Boca Chica	NAFKW	occupied	1.3	exotics/habitat enhancement	medium priority
17	Boca Chica	NAFKW	potential	1.0	exotics	low priority
18	Boca Chica	NAFKW	occupied	4.4	none	
19	Boca Chica	NAFKW	occupied	11.3	exotics/habitat enhancement	medium priority
20	Boca Chica	NAFKW	occupied	4.1	habitat enhancement	low priority
21	Boca Chica	NAFKW	occupied	9.6	exotics/habitat enhancement	medium priority
22	Boca Chica	NAFKW	occupied	1.4	exotics	
23	Boca Chica	NAFKW	occupied	10.9	exotics/habitat enhancement	medium priority
24	Boca Chica	NAFKW	occupied	2.0	none	

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
25	Boca Chica	Private	occupied	1.7	exotics/habitat enhancement	medium priority
26	Boca Chica	NAFKW	occupied	5.1	exotics	medium priority
28	Saddlebunch	USFWS	potential	0.1	none	
29	Saddlebunch	NAFKW	occupied	4.4	exotics	high priority
30	Saddlebunch	NAFKW	occupied	1.8	none	
31	Sugarloaf	Private	occupied	5.0	exotics/predator control	high priority
32	Sugarloaf	Private	occupied	10.0	exotics	high priority
33	Sugarloaf	Mixed	occupied	21.5	exotics/predator control	medium priority
34	Sugarloaf	Private	occupied	8.4	exotics/predator control	high priority
35	Sugarloaf	Private	occupied	2.3	trash	low priority
36	Sugarloaf	Private	potential	10.6	exotics/trash	low priority
37	Sugarloaf	Private	potential	4.2	exotics/predator control	low priority
38	Sugarloaf	Private	potential	6.3	exotics/predator control	low priority
39	Sugarloaf	Mixed	potential	3.2	exotics/predator control	low priority
40	Sugarloaf	Private	potential	1.2	exotics/predator control	low priority
41	Cudjoe	Private	potential	3.2	exotics/trash	low priority
42	Cudjoe	USFWS	potential	5.4	none	
43	Cudjoe	Private	potential	2.6	exotics	low priority
44	Summerland	Mixed	potential	1.8	exotics	medium priority
45	Ramrod	Private	potential	3.0	exotics	low priority
46	Middle Torch	USFWS&State	potential	3.7	exotics	low priority
47	Middle Torch	Private	potential	4.8	exotics	low priority
48	Big Torch	Mixed	potential	4.1	exotics/predator control	medium priority
49	Big Torch	Mixed	potential	14.6	exotics	medium priority
50	Big Torch	Mixed	potential	1.1	none	
51	Little Torch	TNC	potential	5.4	exotics	low priority
52	Big Pine	USFWS&State	occupied	51.2	exotics/habitat enhancement	low priority
53	Big Pine	Mixed	occupied	44.0	exotics	medium priority
54	Big Pine	SFWMD	occupied	11.9	exotics/predator control	medium priority
55	Big Pine	Mixed	occupied	5.4	exotics/trash	medium priority

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
56	Big Pine	Private	Potential	1.3	habitat enhancement/predator contro	low priority
57	Big Pine	Private	Potential	0.3	exotics	medium priority
58	Big Pine	USFWS	Potential	1.2	none	
59	No Name	USFWS	Potential	1.7	none	
60	Boca Chica	NAFKW	Potential	5.8	exotics/trash	low priority
61	Sugarloaf	Private	occupied	5.1	exotics/predator control	medium priority
62	Sugarloaf	State	occupied	2.6	exotics	low priority
63	Sugarloaf	State	Potential	1.8	exotics/habitat enhancement	low priority
64	Saddlebunch	State	Potential	3.0	exotics	low priority
65	Sugarloaf	Mixed	Potential	0.7	none	
66	Sugarloaf	USFWS	Potential	1.5	none	
67	Cudjoe	County&USFWS	Potential	5.3	none	
68	Cudjoe	USFWS	Potential	1.7	exotics	low priority
69	Cudjoe	USFWS	Potential	1.0	none	
70	Summerland	County	Potential	2.1	trash	low priority
71	Boca Chica	NAFKW	Potential	1.0	habitat enhancement/trash	low priority
72	Summerland	Mixed	Potential	6.1	exotics	low priority
73	Summerland	Mixed	Potential	3.3	trash	low priority
74	Summerland	Mixed	potential	8.1	trash	low priority
75	Ramrod	Private	not surveyed	0.4	not surveyed	
76	Ramrod	Private	potential	2.0	none	
77	Ramrod	Private	not surveyed	3.3	not surveyed	
78	Big Torch	Private	not surveyed	2.7	not surveyed	
79	Big Torch	USFWS	potential	5.3	none	
80	Big Torch	Mixed	potential	2.3	none	
81	Big Torch	USFWS	potential	1.2	not surveyed	
82	Boca Chica	NAFKW	potential	2.1	trash (low)	low priority
83	Big Torch	Private	potential	0.8	none	
84	Big Torch	Mixed	potential	7.5	none	
85	Big Pine	TNC&State	occupied	0.7	none	

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
86	Big Pine	Mixed	occupied	15.8	exotics/trash	medium priority
87	Big Pine	USFWS	potential	4.4	none	
88	Big Pine	Mixed	occupied	6.7	none	
89	Big Pine	Mixed	potential	5.8	habitat enhancement	medium priority
90	Big Pine	Mixed	occupied	4.6	exotics	medium priority
91	Snipe Point	USFWS	not surveyed	2.1	not surveyed	
92	Big Johnson	USFWS	potential	1.3	none	
93	Boca Chica	NAFKW	occupied	5.9	exotics	medium priority
94	Big Johnson	USFWS	potential	2.5	none	
95	No Name	USFWS	occupied	1.7	none	
96	Little Johnson	State	potential	1.5	habitat enhancement	low priority
97	Mud	USFWS	not surveyed	0.8	not surveyed	
98	Marvin	USFWS	not surveyed	0.7	not surveyed	
99	Little Pine	USFWS	occupied-reintroduced	10.5	none	
100	Hopkins	Private	not surveyed	1.0	not surveyed	
101	Cook	Private	not surveyed	2.4	not surveyed	
102	Boca Chica	NAFKW	occupied	2.8	none	
103	Saddlehill	Private	potential	2.4	exotics/trash	medium priority
104	Big Pine	USFWS	potential	1.1	none	
105	Saddlebunch	USFWS	occupied	2.4	none	
106	Saddlebunch	Mixed	occupied	9.3	none	
107	Saddlebunch	USFWS	occupied	0.4	none	
108	Saddlebunch	Private	occupied	3.5	none	
109	Sugarloaf	Private	potential	1.1	none	
110	Big Munson	Private	potential	9.8	habitat enhancement/trash	low priority
111	Big Pine	Mixed	occupied	14.8	exotics/trash	medium priority
112	Big Pine	USFWS	potential	1.8	none	
113	Big Pine	Private	potential	0.8	habitat enhancement	low priority
114	Saddlebunch	USFWS	potential	0.4	habitat enhancement/trash	low priority
115	Big Pine	Mixed	occupied	6.7	exotics	medium priority

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
116	Big Pine	USFWS	occupied	3.8	none	
117	Big Pine	Mixed	occupied	7.4	exotics/trash/revegetation	medium priority
118	Mayo	USFWS	occupied	4.4	none	
119	Mayo	USFWS	occupied	4.9	none	
120	Porpoise	USFWS	potential	2.4	none	
121	Annette	USFWS	occupied	23.6	none	
122	Big Pine	Mixed	occupied	34.5	exotics	medium priority
123	Sugarloaf	State	occupied	2.7	habitat enhancement	
124	Big Pine	Private	potential	4.2	hardwood control	low priority
125	Sugarloaf	State	potential	1.8	exotics/habitat enhancement	low priority
126	Sugarloaf	Private	occupied	6.7	none	
127	Big Pine	Mixed	potential	2.2	exotics	low priority
128	Saddlebunch	USFWS	potential	1.2	habitat enhancement	
129	Water	USFWS	potential	1.9	reintroduction	high priority
130	Big Pine	Mixed	potential	2.3	predator control	low priority
131	Big Pine	Mixed	potential	1.0	habitat enhancement	low priority
132	Big Pine	USFWS	occupied	19.7	none	
133	Big Pine	USFWS	occupied	0.7	none	
134	Big Pine	USFWS	occupied	4.3	none	
135	Big Pine	USFWS	occupied	0.5	none	
136	Big Pine	USFWS	occupied	0.2	none	
137	Big Pine	USFWS	occupied	0.1	none	
138	Big Pine	USFWS	occupied	5.0	none	
139	Big Pine	USFWS	occupied	0.4	none	
140	Big Pine	USFWS	occupied	1.3	exotics	
141	Big Pine	USFWS	occupied	0.2	predator control	low priority
142	Little Pine	USFWS	occupied-reintroduced	0.4	none	
143	Big Pine	USFWS	occupied	0.1	none	
144	Saddlebunch	USFWS	occupied	0.3	none	
145	Cudjoe	Private	potential	1.1	none	

Table E. 1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
146	Cudjoe	USFWS	potential	2.3	none	
147	Cudjoe	USFWS	potential	0.7	none	
148	Big Pine	Mixed	occupied	4.2	exotics	
149	Saddlebunch	USFWS	potential	0.1	none	
150	Water	USFWS	potential	1.7	reintroduction	high priority
151	Sugarloaf	State	occupied	1.8	none	
152	Boca Chica	NAFKW	occupied	12.8	exotics	medium priority
153	Boca Chica	NAFKW	occupied	0.3	habitat enhancement	low priority
154	Big Torch	State	potential	1.0	none	
155	Boca Chica	NAFKW	occupied	1.1	none	
156	Boca Chica	NAFKW	potential	1.2	exotics/habitat enhancement	medium priority
157	Boca Chica	NAFKW	occupied	1.9	exotics/habitat enhancement/predator control	high priority
158	Big Pine	State	occupied	0.8	none	
159	Little Pine	USFWS	occupied-reintroduced	1.5	habitat enhancement	medium priority
160	Boca Chica	NAFKW	occupied	2.8	exotics/habitat enhancement	high priority
161	Boca Chica	NAFKW	occupied	0.3	exotics/predator control	high priority
162	Saddlebunch	NAFKW	occupied	1.3	exotics	high priority
163	Little Johnson	USFWS&State	potential	5.1	none	
164	East Water	USFWS	potential	0.9	none	
165	Howe	USFWS	occupied	15.6	none	
166	Howe	USFWS	occupied	3.6	none	
167	Big Torch	USFWS	potential	3.7	none	
168	Big Pine	USFWS	potential	3.0	none	
169	Boca Chica	NAFKW	occupied	0.7	exotics	medium priority
170	Boca Chica	NAFKW	occupied	0.9	none	
171	Boca Chica	NAFKW	occupied	1.4	exotics	medium priority
172	Boca Chica	NAFKW	occupied	1.7	exotics	medium priority
173	Boca Chica	NAFKW	occupied	3.7	exotics	medium priority
174	Boca Chica	NAFKW	occupied	2.4	exotics	medium priority

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
175	Boca Chica	NAFKW	occupied	0.5	exotics	medium priority
176	Boca Chica	NAFKW	occupied	0.2	none	
177	Boca Chica	NAFKW	occupied	0.3	exotics/trash	low priority
178	Boca Chica	NAFKW	occupied	0.7	exotics	
179	Little Torch	Private	potential	5.1	habitat enhancement	low priority
180	Middle Torch	State	potential	0.7	none	
181	Little Torch	TNC	potential	3.6	none	
182	Little Torch	TNC	potential	0.7	exotics	low priority
183	Big Torch	Mixed	potential	0.5	none	
184	Summerland	Private	potential	0.4	none	
185	Little Torch	Mixed	potential	1.4	none	
186	Middle Torch	USFWS	potential	0.6	none	
187	Sugarloaf	County	potential	0.2	predator control	low priority
188	Big Torch	USFWS	potential	5.4	none	
189	Big Pine	Mixed	potential	6.8	exotics/predator control	low priority
190	Big Pine	Private	potential	1.1	predator control	low priority
191	Sugarloaf	Private	occupied	1.1	none	
192	Sugarloaf	Mixed	occupied	0.2	none	
193	Sugarloaf	State	occupied	2.1	exotics	medium priority
194	Sugarloaf	State	occupied	4.0	exotics	medium priority
195	Little Torch	TNC	potential	0.4	exotics	low priority
196	Saddlebunch	USFWS	occupied	0.4	none	
197	Saddlebunch	USFWS	occupied	0.7	none	
198	Sugarloaf	County	potential	1.0	exotics/predator control	low priority
199	Saddlebunch	State	potential	0.6	exotics	low priority
200	Saddlebunch	USFWS	potential	0.4	none	
201	Saddlebunch	USFWS	potential	1.2	habitat enhancement	
202	Saddlebunch	USFWS	occupied	0.6	habitat enhancement	
203	Big Pine	USFWS	potential	2.1	exotics	low priority
204	Saddlebunch	NAFKW	occupied	4.2	exotics	high priority

Table E.1. (continued)

Patch ID	Key	Ownership	Occupancy status	Hectares	Restoration needs	Priority
205	Saddlebunch	NAFKW	occupied	0.4	none	
206	Saddlebunch	NAFKW	occupied	0.7	exotics	high priority
207	Sugarloaf	Private	occupied	0.3	exotics/predator control	high priority
208	Sugarloaf	County	potential	0.1	exotics/predator control	low priority
209	Cudjoe	Private	potential	0.6	exotics/habitat enhancement	low priority
210	Geiger	NAFKW	potential	0.2	exotics/predator control	low priority
211	Geiger	NAFKW	potential	0.1	exotics	
212	Little Pine	USFWS	potential	0.7	none	
213	Water	USFWS	potential	0.7	none	
214	Cudjoe	USFWS	potential	0.5	none	
215	Cudjoe	USFWS	potential	0.1	none	
216	Cudjoe	USFWS	potential	0.2	none	
217	Cudjoe	USFWS	potential	0.2	none	
218	Cudjoe	USFWS	potential	0.6	none	
219	Cudjoe	USFWS	potential	0.7	none	
220	Cudjoe	USFWS	potential	0.3	none	
221	Cudjoe	USFWS	potential	0.7	none	
222	Cudjoe	USFWS	potential	0.9	none	
223	Cudjoe	USFWS	potential	0.4	none	
224	Cudjoe	Mixed	potential	2.6	exotics	
225	Cudjoe	USFWS	potential	0.4	none	
226	Cudjoe	USFWS	potential	0.6	none	
227	Cudjoe	USFWS	potential	0.5	none	
228	Saddlebunch	Private	occupied	2.7	exotics	medium priority
229	No Name	USFWS	potential	1.9	habitat enhancement	low priority

Table E.2 Description of restoration needs for core habitat patches of the Lower Keys marsh rabbit.

ID	Description of restoration needs
1	Trash removal necessary
2	None
3	None
4	Exotic plant species present (e.g. *Casuarina*)
5	Enhance habitat by re-vegetating rocky areas; *Schinus* present
6	Exotic vegetation present
7	*Casuarina*, *Schinus terebinthifolia*; large areas of sparse vegetation where enhancement might help
8	Many exotic plants (lead tree, *Schinus*) and some scarified areas that might be re-vegetated
9	*Schinus terebenthifolia* on the south boundary of the patch and along ditches in buttonwood areas; fire ants present
10	Re-vegetation of adjacent areas would increase the amount of habitat
11	Perhaps control of feral and domestic cats would help; lead tree and *Schinus*
12	None
13	Perhaps control of feral and domestic cats would help
14	Disturbed area; habitat enhancement through planting native grasses could help
15	Some human trash and some *Schinus terebinthifolia*
16	Some scarified areas might be re-vegetated; *Schinus* and *Mahoe*
17	Exotic plants present, especially *Schinus terebinthifolia*
18	None
19	Large areas of Schinus and Leucaena; note: these appear to be providing cover for rabbits so cover must be provided before their removal
20	Perhaps habitat enhancement through establishment of more grasses on south side
21	*Casuarina* present; patches of *Leucaena* appear to be providing cover for rabbits, so cover must be provided before their removal
22	*Casuarina* and *Schinus* present
23	Adjacent scarified, rocky land could be re-vegetated; *Schinus terebinthifolia* and other exotics
24	None
25	*Casuarina* removal; perhaps creation of more cover
26	*Casuarina equisitifolia* present
28	None
29	Some exotics in the sourthern portion (e.g. *Casuarina, Schinus terebinthifolia*)
30	None
31	*Schinus* and *Casuarina* present; cats used to be present in large numbers
32	*Casuarina*, *Schinus*, *Hibiscus tiliaceus*, *Zoysia* present
33	Some exotics, mostly along roadside and just northeast of signal tower; cats present around Munder household
34	Many *Casuarina* present plus *Schinus*; cats could be a problem given proximity to houses
35	Trash (appliances, broken glass, etc.) removal necessary
36	A few *Casuarina* near road; one pile of trash
37	*Casuarina equisitifolia* present; cats could be a problem given proximity to houses
38	*Casuarina equisitifolia* present; cats could be a problem given proximity to houses
39	Exotics along south edge; some *Casuarina* in center as well; cats could be a problem given proximity to houses
40	*Schinus* and *Casuarina* present along road; cats could be a problem given proximity to houses
41	Trash removal necessary; some exotic plants present along the road
42	None

Table E.2. (continued)

ID	Description of restoration needs
43	Some exotics along hammock and in southeast
44	Patches of thick *Schinus terebinthifolia* throughout
45	Some exotics near roadway; cats may be a problem given proximity to development
46	Saw one *Casuarina equisitifolia*
47	Seaside mahoe and *Zoysia* present
48	Dogs were seen loose in the area
49	*Schinus* present in hammock and freshwater hardwoods in the north
50	None
51	Cats may be a problem given proximity to development
52	N. Silvy reports that this area is more overgrown with hardwoods than in the past; rocky area might be re-vegetated; *Schinus* present
53	Exotic plants along Gulfstream
54	Small *Casuarina* present; cats may be a problem given proximity to houses
55	Trash removal necessary; small *Casuarina* spread throughout, mainly north
56	Hurricane Geroges may have altered vegetation; hardwood control and planting bunch grasses to increase cover might help; cats abundant in the area
57	*Schinus terebinthifolia* present
58	Hurricane probably altered the vegetation
59	None
60	Exotic plant species (especially *Schinus* and *Colubrina*) and trash present
61	*Schinus terebinthifolia*, *Casuarina equisitifolia*, and mahoe present; many cats in northern portion.
62	*Casuarina equisitifolia* present
63	*Casuarina equisitifolia* present; perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
64	*Casuarina equisitifolia* nearby
65	None
66	None
67	None
68	*Casuarina* present nearby
69	None
70	*Schinus terebinthifolia* along the roadside
71	Human trash is present; very little grass cover; perhaps hardwood removal and planting of grasses would help.
72	*Schinus terebinthifolia* along the roadside
73	Trash removal necessary; fire ants present
74	Exotics along roadside (e.g. a *Casuarina*); some minor trash removal necessary
75	not surveyed
76	None
77	not surveyed
78	not surveyed
79	None
80	None
81	not surveyed
82	Human trash is present (probably washed in by hurricane)
83	None
84	None

Table E.2. (continued)

ID	Description of restoration needs
85	None
86	Trash along north road; *Casuarina* present
87	None
88	None
89	Perhaps planting bunch grasses on the beach berm could return the area to pre-hurricane vegetation
90	*Casuarina* spread throughout; most in south and east.
91	not surveyed
92	None
93	Exotic plants present, especially *Schinus*
94	None
95	None
96	This area is badly in need of increased cover; uninhabitatble in its current state
97	not surveyed
98	not surveyed
99	None
100	not surveyed
101	not surveyed
102	None
103	*Schinus terebinthifolia* and *Colubrina* are abundant; trash on the berm from storms
104	None
105	None
106	None
107	None
108	None
109	None
110	Planting of bunch grasses along beach berm and trash removal would help
111	*Casuarina* in northwest side; old tailer home on east side
112	Impacted by hurricane and perhaps sea level rise; not sure what could be done
113	Private property; appears mowed; habitat enhancement needed
114	Human trash is present; perhaps cover could be improved by planting bunchgrasses
115	*Casuarina* in north along mosquito ditches; *Schinus terebinthifolia* in southeast; cat tracks
116	None
117	*Casuarina* present; trash present at end of road in middle of patch; part of road could be revegetated
118	None
119	None
120	None
121	None
122	*Casuarina* are present along mosquito ditches
123	Perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
124	T. Wilmers reports that this area is more overgrown with hardwoods than in the past
125	*Casuarina equisitifolia* present; perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
126	None

Table E.2. (continued)

ID	Description of restoration needs
127	One *Causarina* individual seen
128	Perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
129	Reintroduction
130	Cats may be a problem given proximity to houses
131	Much of the area is cleared of vegetation
132	None
133	None
134	None
135	None
136	None
137	None
138	None
139	None
140	*Schinus* present
141	I have seen a cat in the area
142	None
143	None
144	None
145	None
146	None
147	None
148	*Casuarina* spread throughout
149	None
150	Perhaps reintroduction of rabbits
151	None
152	Exotic plants present (e.g. *Casuarina*)
153	Adjacent scarified land could be re-vegetated
154	None
155	None
156	Many *Casuarina* have been removed; re-vegetation of scarified areas is necessary
157	*Leucaena leucocephala* and *Casuarina* present; fire ants present; scarified areas could be re-vegetated; cats seen nearby
158	None
159	Over time, hardwoods might take over much of the site if not controlled
160	Disturbed site covered with many vines and exotics (e.g. *Schinus*); fire ants present; habitat enhancement might help
161	Cats seen nearby; *Casuarina* present
162	Some invasive exotic plant removal needed
163	None
164	None
165	None
166	None
167	None
168	None
169	Exotic plants present, especially *Schinus*

Table E.2. (continued)

ID	Description of restoration needs
170	None
171	Exotics present, mainly *Schinus*; note: exotics may be providing cover for rabbits
172	*Schinus* and *Leucaena*; note: *Leucaena* is acting as cover for rabbits
173	*Casuarina* are present throughout the patch
174	Exotic plants present (especially *Casuarina*)
175	*Schinus terebinthifolia* present
176	None
177	Area is surrounded by *Casuarina*; some trash present
178	*Leucaena* present
179	Control of hardwoods could open up more grass in some areas
180	None
181	None
182	*Casuarina* along north half
183	None
184	None
185	None
186	None
187	Cats could be a problem given proximity to houses
188	None
189	*Casuarina* spread throughout; feral cats likely present
190	Cats and dogs could be a problem
191	None
192	None
193	*Casuarina* in north bend of patch
194	*Casuarina* in north part of patch
195	*Casuarina equisitifolia* present
196	None
197	None
198	Exotic plants present, especially *Casuarina*; cats could be a problem given proximity to houses
199	*Casuarina equisitifolia* can be found nearby
200	None
201	Perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
202	Perhaps some hardwoods could be cut back to promote grass growth; perhaps planting of *Spartina spartinae*
203	Australian pine present in the west end of the patch; many cats in the area
204	Exotic plant species present
205	None
206	Some invasive exotic plant removal needed
207	Exotic plants present; cats used to ba a major problem
208	*Schinus* present along road; cats could be a problem given proximity to houses
209	Exotic plant species are present, particularly *Schinus*; Higher ground is highly distrubed with little grass
210	*Schinus terebinthifolia* present; cats likely a problem
211	*Schinus* present
212	None

Table E.2. (continued)

ID	Description of restoration needs
213	None
214	None
215	None
216	None
217	None
218	None
219	None
220	None
221	None
222	None
223	None
224	*Schinus* and ornamental flowers present in northern section
225	None
226	None
227	None
228	*Schinus terebinthifolia* and *Casuarina equisitifolia* present
229	According to M. Folk, the area used to support more *Spartina*

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Environmental Consultant, Ecology and Environment, Inc., September 2002–present.

Research Assistant, Archbold Biological Station, Lake Placid, FL, August 1999–July 2000.

Intern, Center for Wildlife Management Studies, Kenya, June 1998–May 1999.

PUBLICATION

Lewis, T.L. and C.A. Faulhaber. 1999. Home ranges of spotted turtles (*Clemmys guttata*) in southwestern Ohio. *Chelonian Conservation and Biology* 3(3):430–434.

PROFESSIONAL PRESENTATIONS

Reintroduction as a conservation strategy for the Lower Keys marsh rabbit. 12th Colloquium on the conservation of mammals in the southeastern United States. Starkville, Mississippi, 2003.

Home ranges of spotted turtles (*Clemmys guttata*) in southwestern Ohio. National Conference on Undergraduate Research, Ocean City, Maryland 1998.

OTHER RESEARCH AND VOLUNTEER EXPERIENCE

Key deer (*Odocoileus virginianus clavium*) research volunteer**,** National Key Deer Refuge, Big Pine Key, FL, May 2001–present.

Home ranges of the spotted turtle (*Clemmys guttata*) in southwestern Ohio. Summer 1996–Fall 1998.

Tree species dynamics of a forest stand in Glen Helen Nature Preserve, Ohio. Fall 1998.

Received the Roger Conant Research Fellowship from the Toledo Zoological Society to study the Karner blue butterfly (*Lycaedes melissa samuelis*), Edward's hairstreak (*Satyrium edwardsii*), and Silver-bordered fritillary (*Bolaria selene*). Summer 1997.

Ecology of Ixodid ticks on a private game ranch in Kenya. Spring 1997.

Effects of environmental factors on feeding behavior of blue tang (*Acanthurus coeruleus*), San Salvador, the Bahamas. June, 1996.

Behavior and time use of spotted turtles (*Clemmys guttata*) in southwestern Ohio. Spring 1995.